The Development of Vascular Surgery

Michael E. DeBakey, MD, Houston, Texas

Reprinted from the June issue

The American Journal of Surgery

A Yorke Medical Journal
Published by Technical Publishing Company,
a Division of Dun-Donnelley Publishing Corporation,
a Dun & Bradstreet Company,
666 Fifth Avenue, New York, New York 10019

Printed in the U.S.A.

The Development of Vascular Surgery

Michael E. DeBakey, MD,* Houston, Texas

I should like to express my grateful appreciation for the privilege of joining the distinguished surgeons on this program, all of whom have the highest respect and esteem of surgeons throughout the world. It is a great honor to be associated with them, especially since one of them is the professor who started me on my surgical career and to whom I owe so much, Dr. Alton Ochsner.

It is almost impossible to discuss the field of vascular surgery without indicating that many scientists around the world have contributed to our knowledge in this field. Those of us who have followed this field carefully throughout the past several decades know that many basic contributions by scientists throughout the world made it possible to perform the vascular procedures that we do routinely today. I could not help thinking about this while Dr. Warren Cole was giving his interesting description of the development of cholecystography, this wonderful contribution to clinical medicine. His story illustrates the importance of the contributions of the basic sciences because without them we would have no foundation on which to build. We are constantly adding to the contributions of our predecessors or contemporaries. Unfortunately, time does not permit me to refer to all or even to a selected group of scientists who have contributed to our knowledge of vascular surgery. I have, on occasions, referred to them in my publications, and I shall refer to some in this discussion.

* Chairman of the Cora and Webb Madding Department of Surgery, Baylor College of Medicine, Houston, Texas.

Reprint requests should be addressed to Michael E. DeBakey, MD, Chairman of the Cora and Webb Madding Department of Surgery, Baylor College of Medicine, Houston, Texas 77025.

Supported in part by HEW research grant HL-17269, National Heart and Blood Vessel Research and Demonstration Center, Houston, Texas.

Presented as part of the Inaugural Program of the A. Webb Roberts Center for Continuing Education in the Health Sciences, Baylor University Medical Center, Dallas, Texas, November 3–4, 1972.

Basic Contributions to the Development of Vascular Surgery

I should like to give you an overview of the developments in this field during the past twenty-five years, when the essential advancements occurred. Of these, one of the most eminent was angiography, since it provided the underlying basis for many significant achievements in this field. This important diagnostic procedure made possible the radiographic visualization and precise delineation of disease of the heart and blood vessels. It thus provided the clinical evidence which, along with surgical experience, established the fact that many arterial lesions are well localized, with relatively normal arteries above and below the lesion, and are therefore amenable to surgical treatment.

The announcement of the monumental discovery of the roentgen ray by Roentgen [*1*] in 1895 fired the imagination of medical scientists, who immediately began experimenting with its potential clinical ap-

plication. Within a year after this announcement, two German scientists, Hascheck and Lindenthal [2], first demonstrated the feasibility of radiographic visualization of blood vessels by injecting a radiopaque substance into the blood vessels of an amputated hand. During the next several decades, medical scientists eagerly searched for a solution to the major problem that limited the clinical application of this diagnostic procedure, namely a non-toxic, injectable, radiopaque substance. Among some of the pioneers in this endeavor were two German scientists, Berberich and Hirsch [3], who developed a bromide solution; Brooks [4] in this country, who used a sodium iodide solution; Moniz [5], a Portuguese neurosurgeon, who devised the technic of carotid arteriography to visualize the arteries of the brain; and dos Santos [6] of Lisbon, who developed translumbar aortography. In 1929, Swick [7] of Germany reported the successful use of an organic iodide solution developed by two German scientists, Binz and Räth [8]. His success stimulated subsequent researchers to synthesize other radiopaque substances, which finally led to the effective, safe injectable solutions we use today.

Other important contributions to the development of vascular surgery include the concepts of vascular suturing, thromboendarterectomy, graft replacement, bypass graft, and patch-graft angioplasty. The idea of suturing blood vessels was conceived more than two centuries ago by an Englishman named Lambert [9]. He suggested it to his colleague, Mr. Hallowell, who in turn successfully applied it to an injured artery in the arm of a patient, but the concept languished for more than a century. Toward the latter part of the nineteenth century, the impetus given to experimental surgery by the Listerian doctrine was followed by a great revival of interest in vascular suturing. This interest was further stimulated by Czerny's [10] report of the successful application of this procedure in a patient with an injured internal jugular vein, Postempski's [11] report of its successful use in a wound of the femoral artery, and particularly by the development of endoaneurysmorrhaphy by Matas [12] in 1888.

During the next few decades, intensive activity in this field, both in this country and abroad, distinguished by the work of a number of surgeons, including Eck [13], Murphy [14], Dörfler [15], Payr [16], Carrel [17], Guthrie [18], Bode and Fabian [19], and Jassinowsky [20], clearly demonstrated in experimental animals the feasibility of excising arterial segments and restoring continuity by end-to-end anastomosis or by use of arterial grafts, as well as of transplanting organs such as the kidney and heart. Except for the occasional individual efforts of a few surgeons at the time, little consideration was given to the application of these principles in the treatment of patients with arterial disease. Several factors probably contributed to this delay. For one thing, certain ancillary surgical measures, particularly methods of inducing general anesthesia, blood transfusion, and chemotherapy had not been developed adequately to support extensive vascular procedures. For another, and most important, the technic of arteriography had not yet been sufficiently refined for general and safe clinical use.

The reports, in 1944, of Crafoord and Nylin [21] in Sweden and Gross [22] in Boston of the successful treatment of coarctation by excision and end-to-end anastomosis, and a few years later, of Gross and associates [23,24] and Hufnagel [25], of the use of homografts to repair the defect in the aorta resulting from excision of coarctation, gave considerable impetus to further developments of these approaches to treatment of arterial lesions. Then in 1951, Oudot [26], in Paris, reported the first case of a patient with occlusive disease of the lower abdominal aorta treated by excision and homograft replacement, as originally recommended by Leriche [27] almost thirty years earlier. In the next year, Dubost and associates [28] of Paris performed the first successful resection and homograft replacement of an aneurysm of the abdominal aorta.

Although aortic and arterial homografts used to replace the excised segments during this early period seemed to function satisfactorily, they had a number of disadvantages, including particularly their limited availability and the inconvenience and time consumed in their procurement, sterilization, and preservation. Subsequent experience also showed that the tissue elements of the graft gradually deteriorated and led to complications, such as aneurysmal formation. For these reasons, the need for a more suitable arterial substitute became increasingly apparent. Accordingly, we, as well as other investigators, began directing efforts toward development of an arterial substitute that did not have these disadvantages.

One of the most significant developments in this regard was the observation of Voorhees and coworkers [29] that a fabric woven of Vinyon "N" thread could function satisfactorily as an aortic graft substitute. This stimulated investigators to turn their attention to the use of fabrics made of various materials, such as nylon, Orlon®, Teflon®, Ivalon®, and Dacron®, which were fashioned into tubes by different methods, such as sewing, braiding, heat sealing, knitting, and weaving. In our early experimental

studies, we fashioned tubes from all these materials by sewing the edges of two sheets of the materials (which I did on my wife's sewing machine). Experience in our laboratories indicated that Dacron was the preferable material. After extensive experience in our laboratories showed that these Dacron tubes functioned satisfactorily as arterial substitutes, we cautiously began some clinical investigations (Figure 1). The highly satisfactory results of these early clinical studies encouraged us to find a method of knitting these fabrics into tubes of various sizes. I fortunately had a patient who had had successful resection and homograft replacement of an aneurysm of the abdominal aorta, and he became interested in helping us with this project. Through his interest in a sock-knitting factory, we were able to obtain pertinent information about knitting machines and found, upon visiting this factory, that no such machines were available for our purposes. The suggestion was made, however, that we consult a textile expert, Professor Thomas Edman of Philadelphia. After we discussed with Professor Edman our requirements and objectives, he enthusiastically accepted our request to work with us on this project. He subsequently designed and had built a new knitting machine to produce seamless Dacron tubes in different sizes, as well as in the form of bifurcations. We then experimented with these tubes to determine optimum porosity, and we also experimented with Dacron fabrics; this work ultimately led to a highly satisfactory and effective arterial substitute for clinical use [*30,31*]. In more recent years, we incorporated a Dacron velour surface in the knitting process to enhance tissue adherence and development. Follow-up studies in thousands of patients extending over twenty years have shown excellent long-term function of these Dacron grafts (Figures 2, 8, 24).

Figure 1. Dacron bifurcation graft made of two sheets of Dacron cloth, with edges sewn together on a sewing machine, used to replace defect after resection of aneurysm of abdominal aorta in a 54-year-old white man on September 2, 1954. Patient's postoperative course was entirely satisfactory, and he remained well for many years. He died in 1964, 10 years after this operation, of probable acute myocardial infarction.

Thromboendarterectomy, devised in 1947 by dos Santos [*32*] of Lisbon, is another important technical contribution to vascular surgery. He observed that in some patients the atheromatous occlusive process in the femoral artery was well localized and could be peeled away easily from the remaining wall of the artery by finding the proper cleavage plane. Although the procedure has certain limitations, it proved highly successful in restoring circulation in certain types of arterial occlusive disease and was quickly adopted by vascular surgeons.

Still another important contribution, and one that has proved to be more widely applicable, is the bypass principle devised originally by Kunlin [*33*] of France, with whom I had the good fortune to be associated as an "assistant étranger" while I was studying under Professor René Leriche at the University of Strasbourg. Professor Kunlin observed that in some patients with occlusive disease of the femoral artery, the process was well localized and that the artery distal to the occlusion was relatively normal, the circulation in this distal segment being maintained by collateral vessels. He reasoned that it should be possible to aid nature's efforts to restore circulation around the obstructed segment by attaching a vein graft to an opening in the artery above and below the occlusive process, and thus shunt blood around the obstructed segment. His report of the successful performance of this procedure in a patient suffering from occlusive disease in the superficial femoral artery immediately attracted wide interest, and the principle was rapidly adopted.

Still another useful technical contribution to vascular surgery is patch-graft angioplasty. In our clinical experience with endarterectomy and tubular graft operations for occlusive disease of smaller arteries, such as the internal carotid, vertebral, and even the femoral and popliteal arteries, we found that a certain amount of luminal constriction may result from longitudinal closure of the wound and that in some cases this constriction may be significant. We experimented with various methods of repairing longitudinal and transverse incisions in small arteries in an attempt to overcome this problem. From these studies evolved a method of repair that did not produce luminal constriction. It consisted in placing a patch graft over the incision and suturing the edges of the wound to the edges of the patch graft [*34*]. Of interest in this connection, we found that Carrel [*17*] and Guthrie [*18*] had performed some experiments with the method in 1906 and had concluded that except for experimental purposes, it would probably be rarely used. Contrary to their opinion, it has proved to be a valuable technical procedure that has wide clinical application. Both segments of veins and Dacron grafts may be used for this purpose (Figure 34). It may be used with or without endarterectomy and may be combined with a bypass graft.

One of the most significant developments in vascular surgery has been the evolution of certain concepts concerning diseases of the aorta and major arteries that provide the basis for rational and more effective therapy. Most vascular diseases are of arteriosclerotic or atherosclerotic origin, but regardless of etiology, the concept has evolved that in many forms of aortic and arterial disease the pathologic process is well localized and segmental, with relatively normal, patent proximal and distal arterial beds, and this has provided the basis for effective surgical therapy [*35–38*]. In general, most aortic and

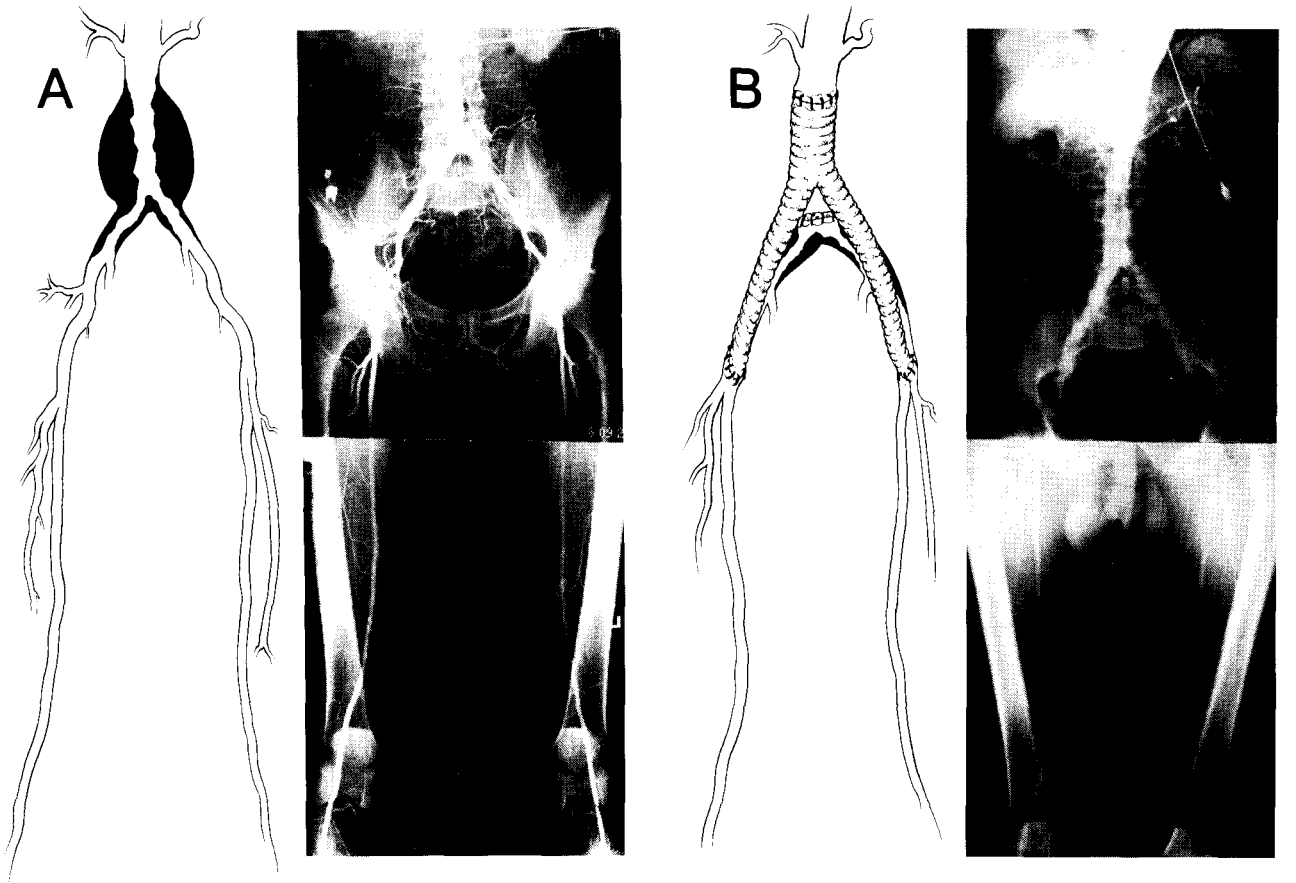


Figure 2. A, drawing and aortogram in a 59-year-old white man with progressive intermittent claudication showing occlusive disease of both external iliac arteries. Patient also had a moderate-sized fusiform aneurysm not visualized in the aortogram because of laminated thrombus formation. B, drawing showing method of resection of aneurysm and replacement with Dacron bifurcation. Patient remains asymptomatic 21 years after operation; postoperative aortogram shows patent functioning graft with good distal circulation.

arterial diseases may be classified into two major categories: occlusive and aneurysmal lesions. There is a tendency for both of these categories of the disease to assume certain characteristic anatomic, pathologic, and clinical patterns of involvement.

Occlusive Disease

In accordance with this concept, it is possible to classify most, if not all, forms of arterial occlusive disease into four major categories involving: (1) the major branches of the aortic arch; (2) the major visceral branches of the abdominal aorta; (3) the terminal abdominal aorta and its major branches; and (4) the coronary arteries.

Major Branches of Aortic Arch

In the first category, occlusive disease of the major branches of the aortic arch, the process tends to assume characteristic patterns with regard to extent and sites of involvement [*39*]. One form of the disease affects predominantly the common carotid arteries at the bifurcation and at the origin of the vertebral arteries (Figures 3, 4). The second form affects predominantly the proximal segments of these vessels as they arise from the aortic arch [*40*] (Figure 5). In both forms the occlusion may be partial or complete, but the important feature is that the disease is usually well localized, with relatively normal, patent distal arterial segments, so that these patterns are amenable to surgical treatment. The clinical significance of these patterns of occlusive disease lies in their association with manifestations of cerebrovascular insufficiency.

The two basic surgical methods of treatment for these forms of occlusive disease consist in endarterectomy or bypass grafting. Our first experience with this pattern of occlusive disease occurred in 1953 [*41*]. The patient, a 53-year-old male bus driver, complained of intermittent episodes of weakness of the right arm and leg, and hesitancy and difficulty in speaking and writing clearly. The only significant

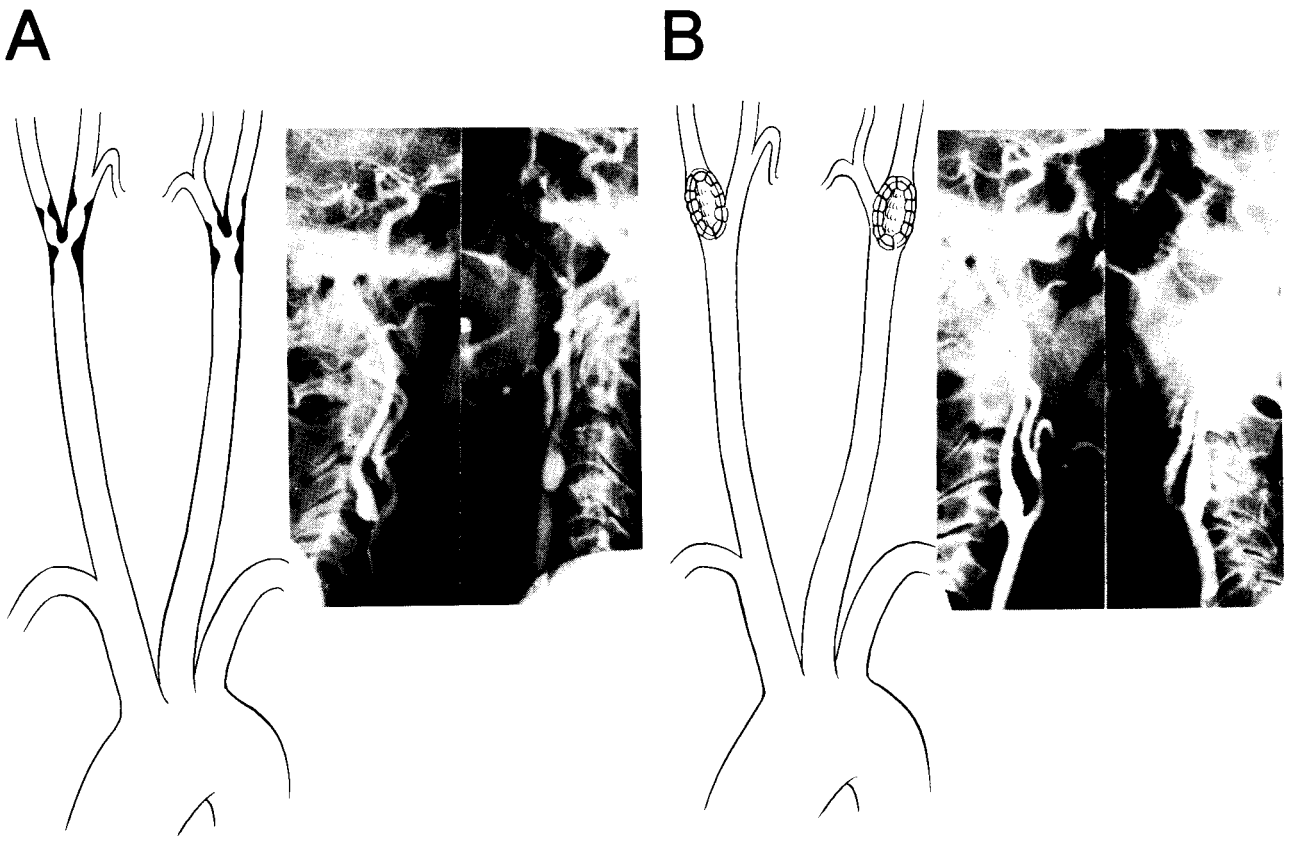


Figure 3. A, drawing and bilateral carotid arteriograms in a 53-year-old white man with transient ischemic episodes of cerebrovascular insufficiency showing severe stenosis of both common carotid arteries at bifurcation and at origin of internal carotid arteries. B, drawing showing method of endarterectomy and patch-graft angioplasty. Patient has remained asymptomatic for almost 20 years after operation; postoperative arteriogram shows restoration of normal lumen and circulation with no evidence of recurrent disease during this time.

physical findings were a weak pulse in the left carotid artery, hyperactive tendon reflexes on the right, and diminished femoral and pedal pulses on the left side. A diagnosis of occlusion of the left internal carotid artery was made on the basis of these and other clinical manifestations. Previous reports of postmortem studies in patients with strokes had shown that in some patients the occlusive process at the bifurcation of the common carotid artery and the origin of the internal carotid artery may be well localized, with a patent distal segment. On this basis, we reasoned that endarterectomy or excision with graft replacement, which experience had shown was effective for such lesions in the lower extremities, might be applicable in this case. Accordingly, I discussed this projected surgical treatment with the patient and members of his family, indicating that, as far as I knew, this operation had never been successfully performed on the carotid artery but that I had had considerable experience with its successful use for similar lesions in the legs. He agreed to have the operation, which I performed on August 7, 1953. After the left common internal and external carotid arteries were exposed, a clamp was applied to the common carotid artery about 2.5 cm below the bifurcation; a longitudinal incision was then made in the common carotid artery and extended above into the internal carotid artery. A well-localized, somewhat ulcerated and necrotic, yellowish-brown, atheromatous plaque was found, producing severe stenosis, with a fresh thrombus superimposed and attached to it and extending into the origin of the internal carotid artery, completely obstructing its lumen. Thromboendarterectomy was then performed, after which there was good retrograde flow from both the internal and external carotid arteries. The arteriotomy was repaired by a continuous suture of fine arterial silk, and the occluding clamp was removed. An arteriogram, made after completion of the operation while the patient was still on the operating table, showed patency of the internal carotid artery and visualization of the middle cerebral artery. The patient was discharged from the hospital on the eighth postoperative day after an uneventful recovery. Follow-up studies showed that he improved progressively and returned to work as a bus driver. An angiogram made a little more than two years after admission showed both common and internal carotid arteries to be patent. The patient had no further manifestations of transient cerebral attacks. He died nineteen years after operation from coronary artery disease.

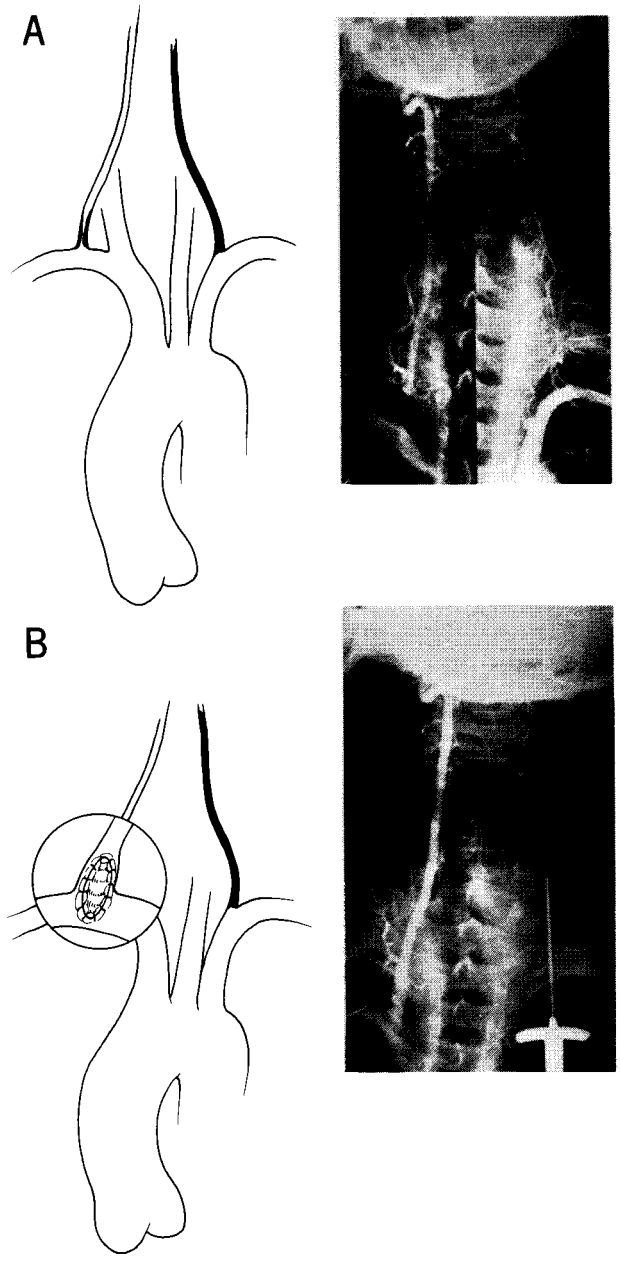


Figure 4. A, drawing and preoperative arteriogram in a 49-year-old white man who had transient episodes of basilar arterial insufficiency, showing complete occlusion of left vertebral and severe stenosis at origin of right vertebral artery from right subclavian artery. B, drawing showing method of endarterectomy with Dacron patch angioplasty. Patient has remained asymptomatic for almost 15 years after operation; arteriogram shows restoration of normal lumen and circulation with no recurrence of occlusive disease since operation.

The favorable result in this case was of considerable significance for several reasons. First, the concept underlying the clinical problem of cerebrovascular insufficiency resulting from extracranial arterial occlusive disease at the time of this patient's operation had not yet been established, although certain reported clinical and pathologic observations suggested it. Second, the findings and the successful

result obtained in this case confirmed the concept that the localized occlusive process in the carotid artery was responsible for the manifestations of cerebral ischemia, and that removal of the occlusive process with restoration of circulation in the arterial bed distal to the occlusion was an effective method of treatment. Finally and most important, it provided considerable encouragement for more intensive investigation of this clinical problem and further application of this method of treatment.

As a result of subsequent extensive clinical, arteriographic, and surgical experience, certain concepts concerning the diagnosis and treatment of cerebrovascular insufficiency were established [*40*]. Thus, it was shown that these occlusive lesions tend to assume distinctive patterns as previously described, that multiple involvement of the major carotid and vertebral arteries is common, and that for this reason as well as because of collateral circulation, the clinical manifestations do not always reflect the exact nature, site, and extent of the occlusive process. It therefore emphasized the critical need for complete angiographic studies for precise diagnosis and effective therapy. From a technical standpoint, we also observed that after endarterectomy, patch-graft angioplasty was usually desirable in order to prevent

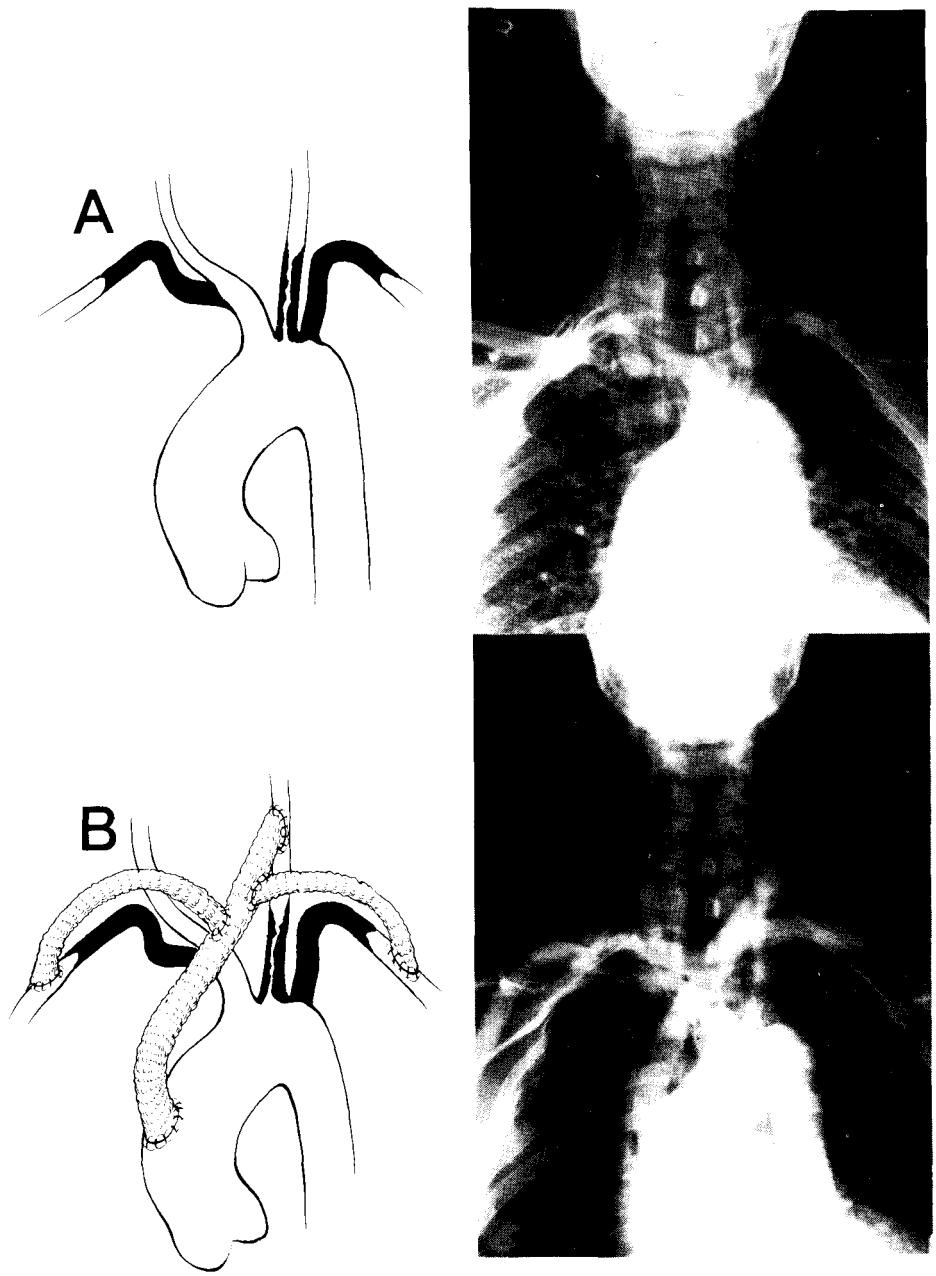


Figure 5. A, drawing and preoperative arteriogram in a 51-year-old white man with manifestations of cerebrovascular insufficiency and intermittent claudication of upper limbs showing complete segmental occlusion of both subclavian arteries and severe but well-localized atherosclerotic occlusive disease at origin of left common carotid artery. B, drawing showing method of Dacron bypass graft from ascending aorta to both subclavian arteries and left common carotid artery. Patient has remained asymptomatic for about 15 years after operation; postoperative arteriogram shows graft functioning well with no recurrence of disease.

narrowing of the lumen after simple suture closure of the arteriotomy and to prevent recurrence of occlusion. In addition, the most effective method of preventing neurologic complications from cerebral ischemia during temporary arrest of circulation in the carotid arteries while performing endarterectomy was found to be use of an internal shunt with a plastic tube.

Characteristically, occlusive disease involving the innominate, common carotid, and left subclavian arteries tends to be well localized near the origin of these arteries with a relatively normal patent distal arterial bed [*39*]. Indeed, we have rarely observed a patient with this form of occlusive disease that did not have a patent segment distal to the lesion. For this reason, virtually all patients with this form of the disease are candidates for operation. In our early experience, we began using endarterectomy for some of these lesions, but we found that the exposure often required an extensive operative procedure. Our

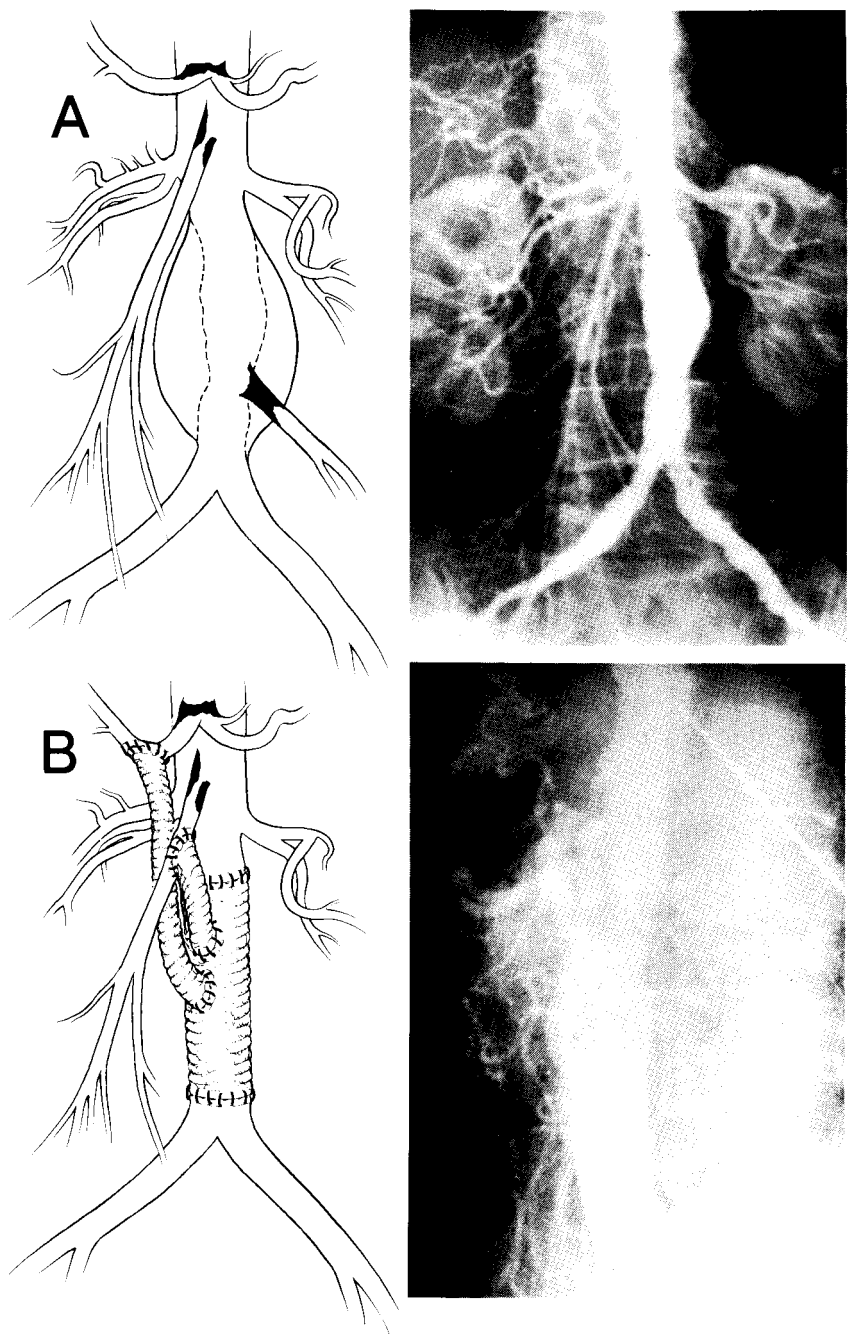


Figure 6. A, drawing and abdominal aortogram in a 58-year-old white woman with abdominal angina and progressive loss of weight, showing fusiform aneurysm of abdominal aorta and severe, well-localized atherosclerotic occlusive disease at origin of celiac and superior and inferior mesenteric arteries. B, drawing showing method of resection of aneurysm with Dacron graft replacement and bypass graft to major branch of celiac artery and superior mesenteric artery; postoperative aortogram shows restoration of circulation to both celiac and superior mesenteric arteries.

gratifying experience with the bypass graft in occlusive disease of the lower extremities suggested that this method of surgical treatment might be preferable. Accordingly, a method of surgical treatment was developed that consisted essentially in anastomosing, end-to-side, a Dacron graft to the ascending aorta, which had been exposed through a small right anterior intercostal incision at about the second or third intercostal space; tunneling the graft into the neck through the thoracic outlet; and attaching the distal end of the graft by end-to-side anastomosis to a patent segment of the artery in the neck [*39,42*]. For multiple lesions multiple branches could be used by attaching the additional grafts to the one attached to the ascending aorta. For some forms of the disease, the bypass grafts could be attached to arteries in the neck without making an incision in the chest. Thus, for occlusive disease of the left subclavian artery with a normal left common carotid artery, the bypass graft could extend from the left common carotid artery to the left subclavian artery. Similarly, in right common carotid arterial occlusion with patent innominate and right subclavian arteries, the bypass graft could be attached to the right subclavian artery and then to the common carotid artery distal to the occlusive process, usually at the bifurcation. These methods of surgical treatment proved to be associated with less surgical trauma and less risk and to provide

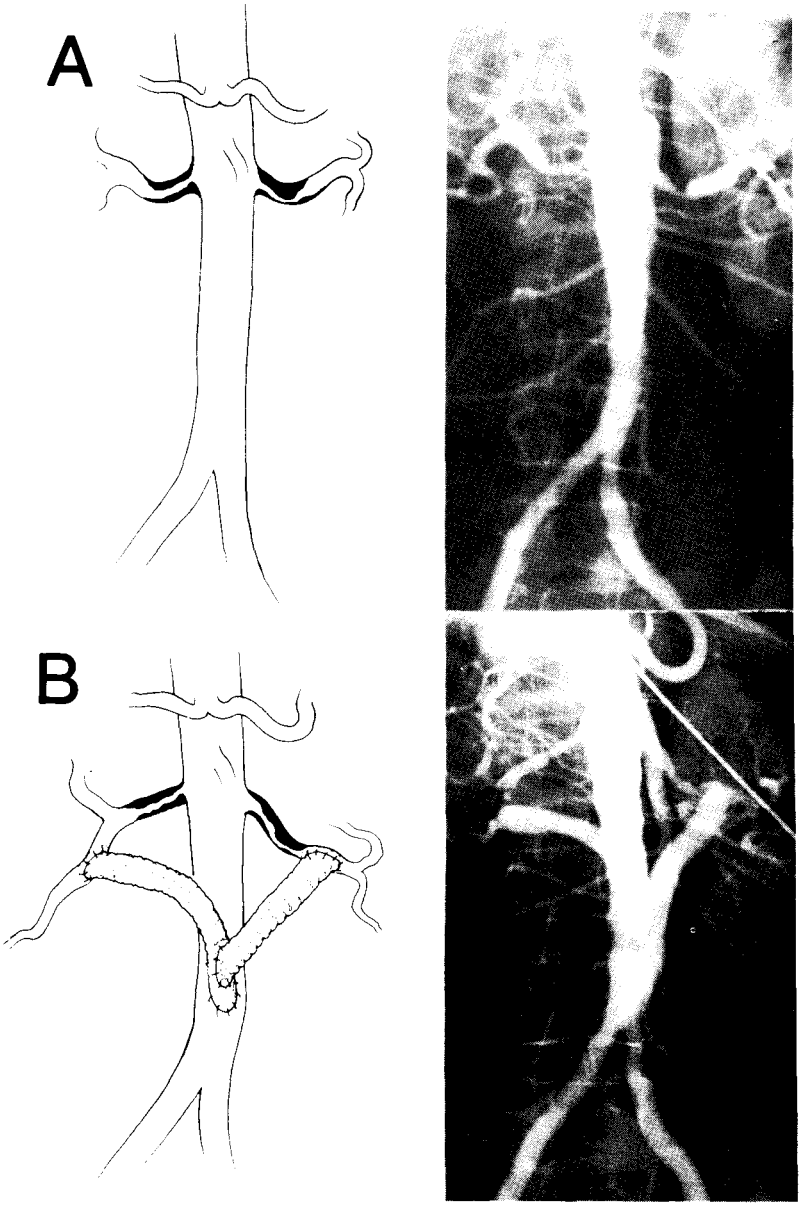


Figure 7. A, drawing and preoperative aortogram in a 56-year-old white woman with severe hypertension (blood pressure 260/150) inadequately controlled by medical therapy. B, drawing showing method of treatment with bypass Dacron grafts from abdominal aorta to both renal arteries. Patient has remained well with well-controlled blood pressure for about 20 years after operation; postoperative aortogram shows well-functioning grafts with normal restoration of circulation to both kidneys and no evidence of recurrence of atherosclerotic disease since operation.

highly gratifying immediate and long-term results.

Major Visceral Branches of Abdominal Aorta

Occlusive disease of the major visceral branches of the abdominal aorta, namely, the celiac, superior mesenteric, and renal arteries, also tends to be characterized by segmental localization, usually near the origin of the arteries from the aorta, with a relatively normal patent distal arterial bed. Here again, these characteristic features of the occlusive process make them amenable to surgical treatment. In patients with involvement of the celiac and superior mesenteric arteries, ischemic disturbances of the gastrointestinal tract, often referred to as abdominal angina, may occur. Although endarterectomy was used in our early experience, it was subsequently found that the bypass graft from the abdominal aorta to a major branch of the celiac or to the superior mesenteric artery, or to both, was preferable, since it was simpler to perform and provided excellent results [*43*] (Figure 6).

Renal Arteries. Occlusive lesions of the renal arteries are often associated with hypertension, which may be difficult to control by medical measures. Whereas atherosclerosis is the underlying pathologic process in most patients, in a significant number, especially relatively young women, the underlying lesion is fibromuscular hyperplasia. Although endarterectomy with patch-graft angioplasty may be used in some patients with highly localized disease, we have found the bypass graft to be preferable in most patients and in all those with fibromuscular hyperplasia [*44*] (Figure 7).

Lower Abdominal Aorta

The next pattern of occlusive disease involves the lower abdominal aorta and its major branches, resulting in intermittent claudication. Again, the occlusive process tends to assume several distinctive characteristics. One of the more common patterns is characterized by localization in the aorto-iliac segment associated with incomplete or complete occlusion of one or both common iliac arteries (Figure 8). In the latter circumstances, the abdominal aorta may become completely occluded by thrombosis up to the origin of the renal arteries. In our early experience, patients with this pattern of the disease were treated by excision and homograft replacement [*45*]. After the introduction of the concept of endarterectomy by dos Santos [*32*], we began to apply this method in patients with this pattern of occlusive disease (Figure 8). Later, after Kunlin [*33*] introduced the bypass principle and as our experience with the bypass graft increased, we reasoned that it could also be applied to this pattern of the disease. We soon found that the bypass graft procedure was far simpler to perform and was equally, if not more, effective in restoring circulation in the lower extremities [*46,47*] (Figure 9). In its application, we found that thromboendarterectomy of the abdominal aorta up to the origin of the renal arteries was sometimes necessary before the proximal end of the graft was attached. The distal ends of the graft might be attached to the external iliac or common femoral arteries, depending on the extent of the occlusive process.

Another characteristic form of this category of occlusive disease is involvement of the superficial femoral arteries with partial or complete obstruction, often localized in the region of the adductor canal but sometimes extending proximally to the origin of the profunda femoris artery, but with a relatively normal patent popliteal artery. Again, in our early experience, we attempted endarterectomy in these cases and even designed a loop to insert into the lumen of the artery after developing a cleavage plane to strip the occlusive lesion in the distal segment [*48*]. Some success with this method was achieved, but we soon learned that it was associated with a number of complications as well as with frequent recurrences (Figure 10). For these reasons, we began using the bypass graft principle, which soon proved to be the procedure of choice in most cases. In this connection, we found that Dacron grafts yielded excellent immediate and long-term results in most patients. In patients in whom the graft must be attached to the popliteal artery below the knee, however, venous autografts are preferable.

Combinations of these patterns, that is, involvement of the aorto-iliac segment and the superficial femoral artery, may also occur, but so long as the lesions are segmental, the bypass graft principle can be applied effectively (Figure 11).

In this category of occlusive disease there remains still another pattern which unfortunately is usually not amenable to surgical treatment. In this form of the disease, the occlusive process involves predominantly the distal arterial bed, beginning often in the popliteal artery and extending down into its major branches for varying distances. Some of these patients may be treated by lumbar sympathectomy (Figure 12). In occasional patients with this pattern, there may be a distal patent segment of one of the major branches of the popliteal artery, so that a long vein bypass can be used. This is sometimes indicated to save the extremity.

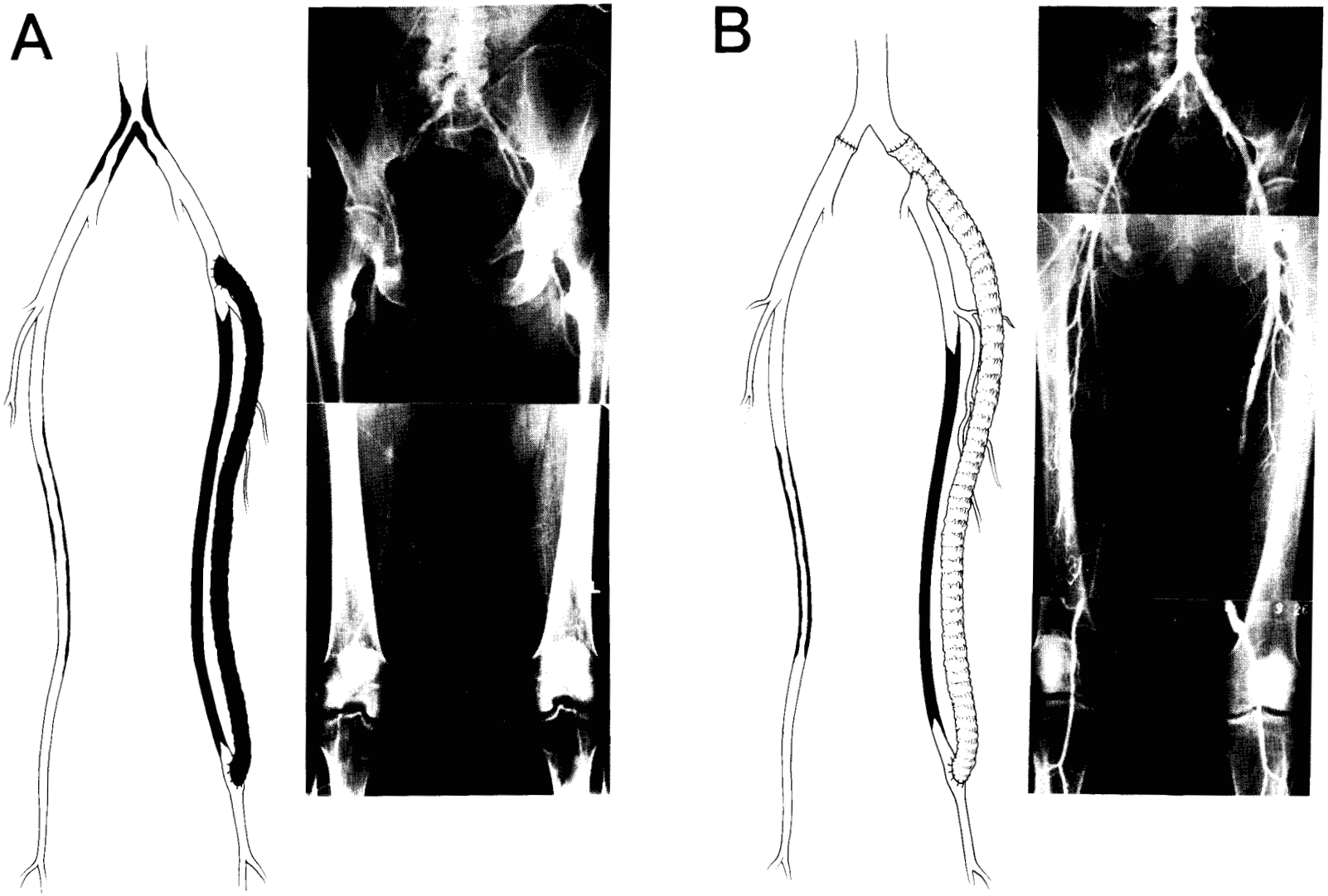


Figure 8. A, drawing and abdominal aortogram in a 53-year-old white man with intermittent claudication of lower limbs, showing severe, localized aorto-iliac occlusive disease and complete occlusion of left superficial femoral artery with occlusion of left femoropopliteal bypass graft performed elsewhere. B, drawing showing method of aorto-iliac endarterectomy with Dacron bypass graft to left popliteal artery. Patient has remained well for 22 years after operation, with only recent development of mild intermittent claudication of artery in right leg not requiring operation; postoperative aortogram shows normally patent aorto-iliac segment and well-functioning graft, with only mild recurrence of occlusive disease in right superficial femoral artery since operation.

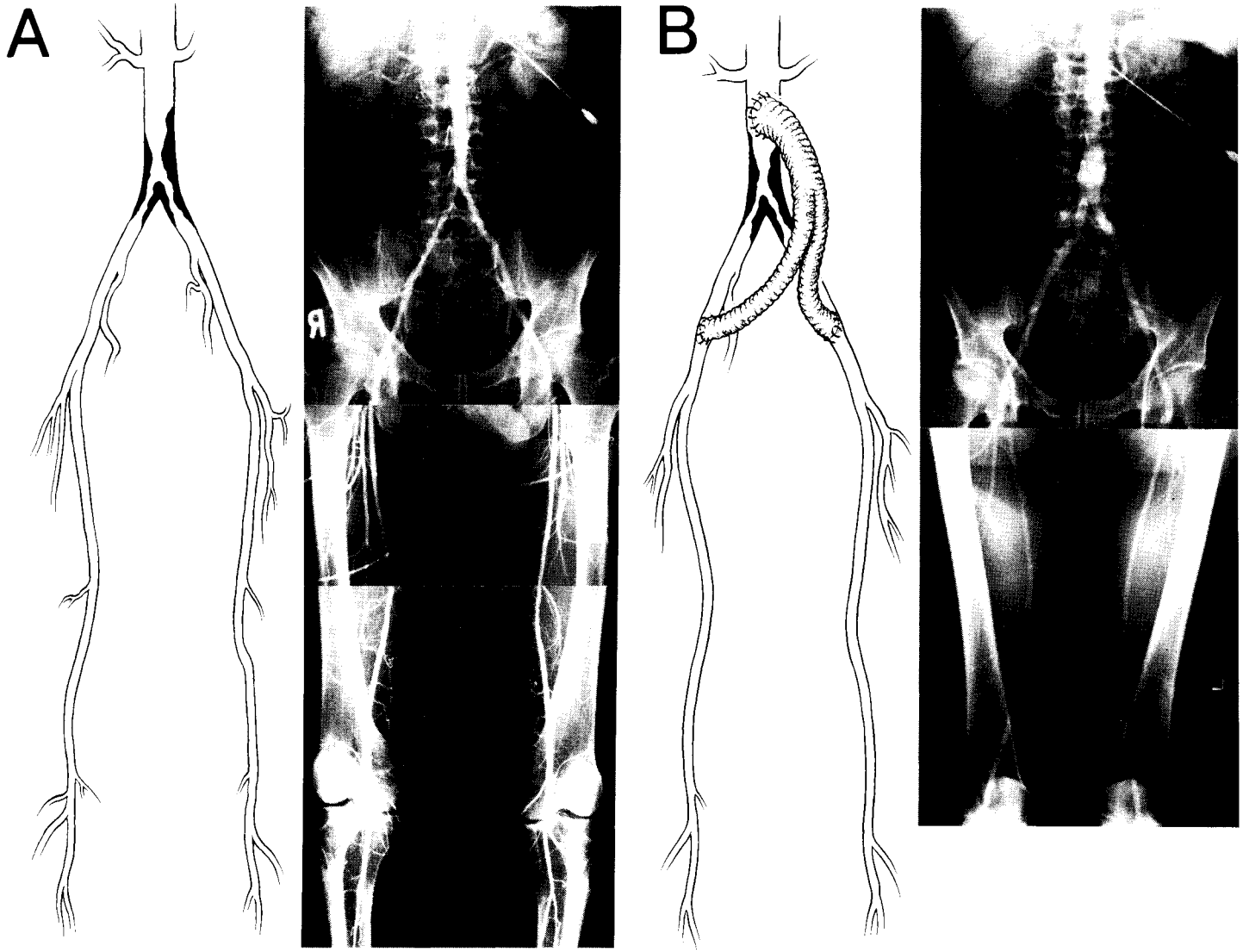


Figure 9. A, drawing and preoperative aortogram in a 48-year-old white man with intermittent claudication of lower extremities showing well-localized atherosclerotic aorto-iliac disease. B, drawing showing method of Dacron bifurcation bypass graft from abdominal aorta to both external iliac arteries. Patient has remained asymptomatic for about 17 years after operation; postoperative aortogram shows restoration of normal circulation through graft with no recurrence of atherosclerotic occlusive disease since operation.

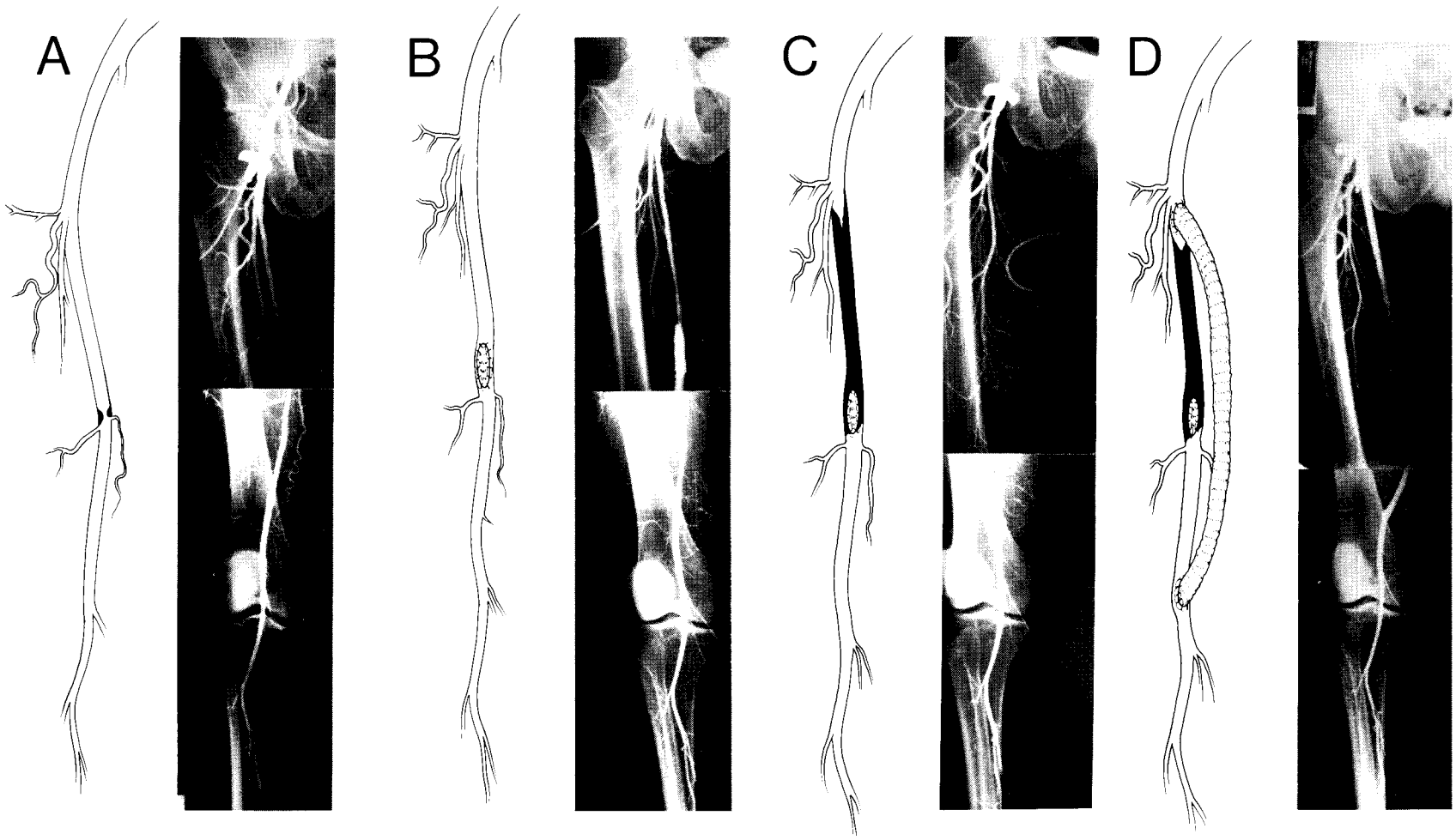


Figure 10. A, drawing and preoperative right femoral arteriogram in a 47-year-old white man with intermittent claudication of right lower extremity, showing well-localized atherosclerotic occlusive disease involving right superficial femoral artery. B, drawing showing method of endarterectomy and patch-graft angioplasty; arteriogram made 4 years after operation shows recurrent stenosis of right superficial femoral artery just proximal to previous endarterectomy. Patient had only mild symptoms at this time and operation was not required. C, drawing and right femoral arteriogram in same patient 3 years later with severe intermittent claudication showing complete occlusion of proximal segment of right superficial femoral artery. D, drawing showing method of surgical treatment consisting in right Dacron femoropopliteal bypass graft. Patient has remained asymptomatic for 10 years after this operation; postoperative arteriogram shows normal restoration of circulation through bypass graft with no evidence of recurrence of disease.

Coronary Arteries

The remaining category of arterial occlusive disease, and perhaps the most important because of its disabling and fatal consequences, affects the coronary arteries. As in the other categories, the occlusive processes in these arteries tend to assume distinctive patterns. In most forms of the disease the occlusive process tends to be well localized with a relatively normal patent distal arterial bed, and is therefore amenable to surgical treatment (Figures 13, 14). In other patterns, however, in which the disease is more extensive and diffuse throughout the arterial bed or involves predominantly the distal arterial bed, surgical treatment is not usually feasible. Here again, in our early experience, we performed endarterectomy with patch-graft angioplasty in patients with proximally situated, well-localized lesions. At the same time, however, in our experimental laboratory we, along with others, were studying the procedure of aorto-coronary bypass [*49–53*]. Like others [*54–59*] we [*53*] experienced sufficient clinical success with endarterectomy and patch-graft angioplasty to encourage their continuous cautious application. Indeed, a few of the patients so treated are still alive and leading normal lives more than fifteen years after operation (Figure 13).

Our initial experience with clinical application of the bypass procedure, and the first successful case in

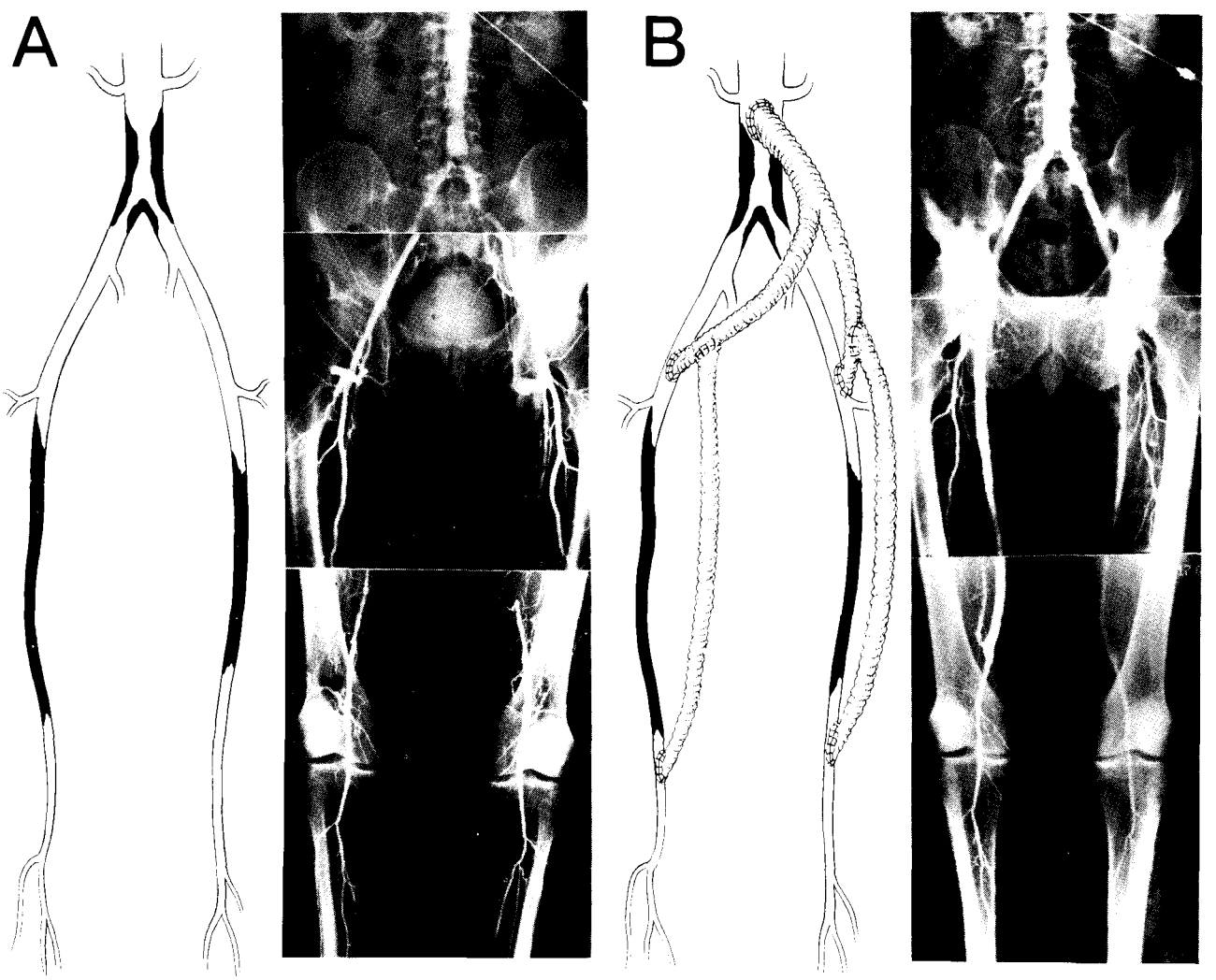


Figure 11. A, drawing and preoperative aortogram in a 55-year-old white man with intermittent claudication of lower limbs showing well-localized aorto-iliac occlusive disease and complete occlusion of both superficial femoral arteries. B, drawing showing method of surgical treatment consisting in Dacron bypass graft from abdominal aorta to both common femoral arteries and both popliteal arteries. Patient has remained asymptomatic for about 15 years since operation with no evidence of recurrent disease as demonstrated by postoperative aortogram showing functioning grafts.

which this procedure was used for coronary artery disease, occurred in 1964 [60]. The patient was a 42-year-old white man suffering with severe angina pectoris uncontrolled by medical therapy. Coronary arteriography showed diffuse narrowing of the right coronary artery and severe stenosis of the left main coronary artery. Operation was performed on November 23, 1964. It was our objective to perform endarterectomy, but after exposing the left main coronary artery and the proximal segments of the anterior descending and circumflex arteries, we found that the disease involved the entire bifurcation. We decided that endarterectomy was not feasible and would be too hazardous. Recalling our experience using aorto-coronary bypass in animals, we decided to perform this procedure instead. Accordingly, a segment of the saphenous vein was removed and prepared for this purpose, and the patient was connected to the heart-lung machine. The reversed vein graft was then attached by end-to-side anastomosis to the left anterior descending coronary artery and the ascending aorta. The patient tolerated the operation well, and his postoperative course was uneventful. He became asymptomatic and resumed

Figure 12. A, drawing and abdominal aortogram in a 66-year-old white man with intermittent claudication of lower limbs showing severe atherosclerotic occlusive disease of both popliteal arteries and their major branches. Patient obtained some improvement after bilateral lumbar sympathectomy.

work. A coronary arteriogram made seven years after operation showed the bypass graft to be functioning well. The successful outcome in this case, as in other first successful cases, provided great encouragement to continue to use this technic, and the subsequent gratifying experience has fully justified this encouragement (Figure 14).

Aneurysmal Disease

I should now like to turn to a consideration of aneurysmal disease. Here again, certain conceptual developments have evolved that have great underlying significance in the treatment of these lesions. First among these is the fact that once an aneurysm has formed through weakening or destruction of the media, regardless of etiology, it tends to progress and ultimately to produce serious and even lethal complications from compression of surrounding structures or from rupture. For this reason, complete removal or obliteration of the aneurysm is an essential therapeutic objective, and herein lies an important conceptual difference in the treatment of an aneurysm as opposed to that of occlusive disease. In aneurysms, the primary objective is removal of the lesion, since its very presence constitutes a threat to life. In occlusive disease, however, restoration of circulation is the primary objective which, once achieved, does not necessarily require removal of the lesion. Restoration of circulation is also desirable, and in most cases, necessary after removal of an aneurysm.

The tendency for aneurysmal disease, like occlusive disease, to assume distinctive patterns with regard to location, extent, and segmental characteristics, with relatively normal arterial segments above and below the pathologic process, is another important conceptual development. Thus, regardless of etiology, extent, or location of the aneurysm, if the proximal and distal vascular segments are relatively normal, the aneurysm is amenable to surgical treatment. In general, three methods of surgical treatment

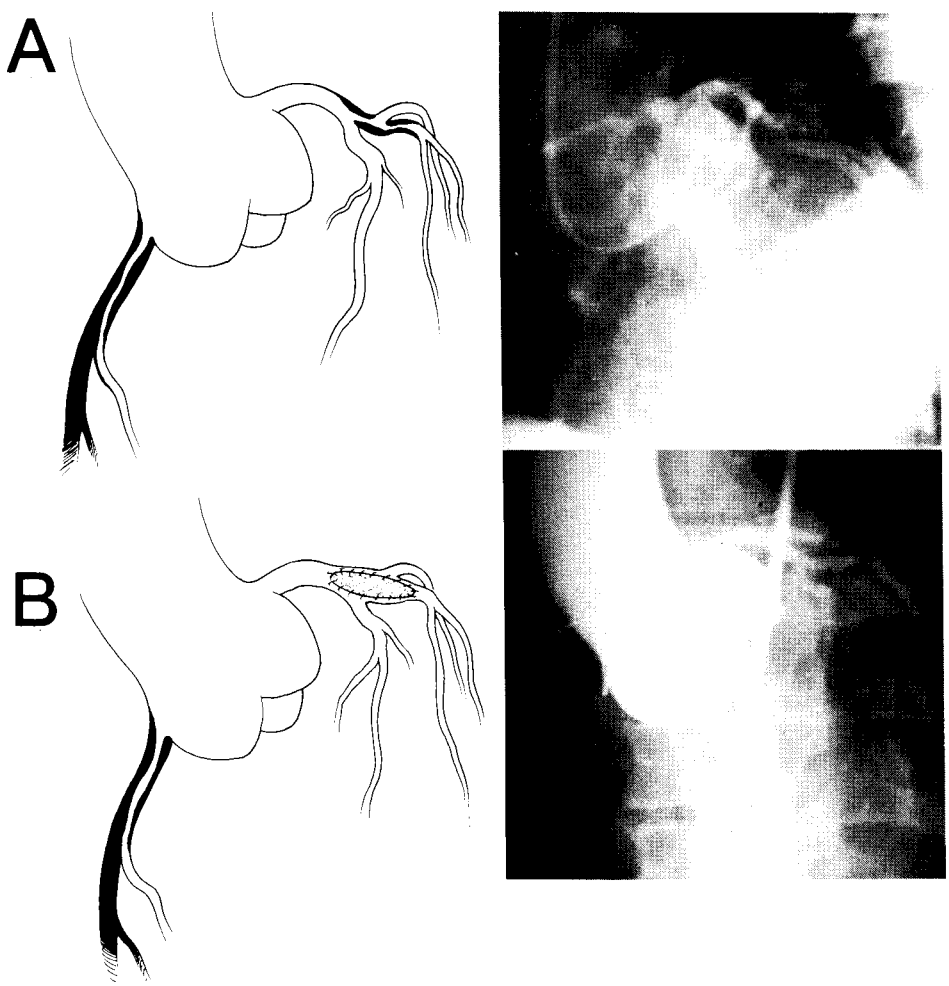


Figure 13. A, drawing and preoperative coronary arteriogram in a 50-year-old white man, with severe, disabling angina not controlled by medical therapy, showing complete occlusion of non-dominant right coronary artery and well-localized, almost complete occlusion of origin of circumflex coronary artery. B, drawing showing method of endarterectomy and autogenous-vein patch-graft angioplasty of circumflex coronary artery. Patient has remained asymptomatic and working for the past 16 years since operation; arteriogram shows restoration of normal circulation with no recurrence of disease since operation.

may be used: (1) excision with graft replacement; (2) obliteration by endoaneurysmorrhaphy, and restoration of circulation with a bypass graft; and (3) excision with patch-graft angioplasty for some sacciform aneurysms.

Abdominal Aorta

Among the various patterns of aneurysmal disease, perhaps the most common is the one involving the abdominal aorta, which characteristically arises just below the origin of the renal arteries and usually extends down to the bifurcation and often beyond to include the common iliac arteries. At the time that we [*61,62*] performed our first successful resection and homograft replacement of such an aneurysm, we were not aware that Dubost [*28*] had performed this same operation. Excision with Dacron graft replacement has now become standard therapy. In some aneurysms associated with occlusive disease of the renal or iliac arteries, bypass graft may be used at the same time to restore normal circulation to these vessels. Temporary arrest of circulation at this level, that is, below the renal arteries, is rarely associated with ischemic disturbances. Technically, it has been found more expeditious to enter the aneurysm after application of proximal and distal occluding clamps, oversew the openings of the lumbar arteries in the posterior wall, and remove the thrombus and intimal lining of the aneurysmal wall rather than to attempt to excise the aneurysm entirely.

Another important technical consideration is the need to encase the graft completely with normal surrounding tissue. The surgical risk in this type of unruptured aneurysm is now extremely low, and the long-term results are excellent. Ruptured aneurysms require emergency operation, the first and primary objective being to arrest circulation in the aorta above the aneurysm at whatever level can be done most rapidly. The risk of operation in these cases remains high, about 35 per cent in our experience.

Descending Thoracic Aorta

The next most common pattern of aortic aneurysm involves the descending thoracic aorta, which characteristically extends from just below the origin of the left subclavian artery down to a varying distance

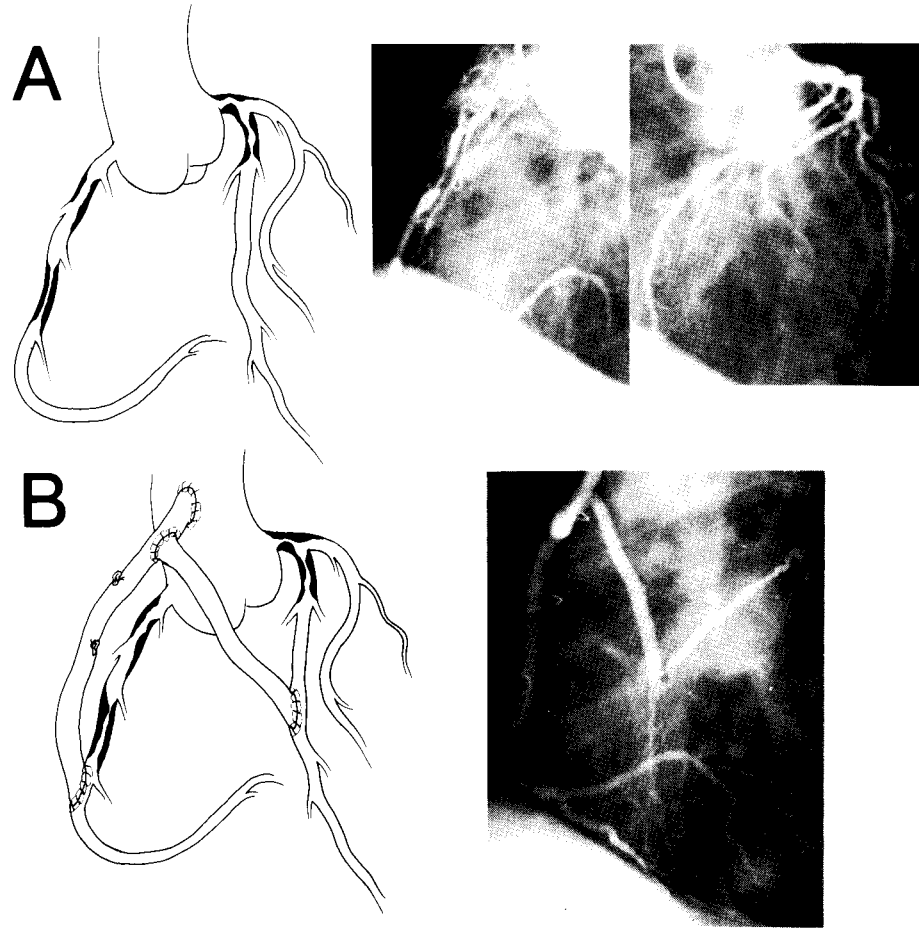


Figure 14. A, drawing and preoperative coronary arteriogram in a 54-year-old white man with severe, disabling angina, showing well-localized atherosclerotic occlusive lesion in proximal segments of right and left anterior descending coronary arteries. B, drawing showing method of surgical treatment with autogenous saphenous vein bypass graft from ascending aorta to right and left anterior descending coronary arteries. Patient has remained asymptomatic for about 9 years after operation; postoperative coronary arteriogram shows graft functioning well.

above the diaphragm. Our initial experience [*63,64*] with this type of aneurysm, and the first successful application of resection and graft replacement for a fusiform aneurysm of the descending thoracic aorta, was in a 46-year-old white man who was admitted to The Methodist Hospital on December 31, 1952, complaining of progressively severe lower back, left lower abdominal, and inguinal pain of several months' duration. Plain roentgenograms showed a large mass behind the heart just above the diaphragm and extensive erosion of the bodies of the ninth through the twelfth thoracic vertebrae and the first lumbar vertebra. Aortography disclosed a large fusiform aneurysm of the lower descending thoracic aorta (Figure 15). After explaining the problem to the patient and recommending operation, I indicated that although we had successfully performed the operation for aneurysm of the lower abdominal aorta, we had not previously had any surgical experience with aneurysms in the descending thoracic aorta nor were we aware of any such experience elsewhere. I also indicated that the risks might be considerable, but there was no other form of effective therapy for his condition. The patient agreed to accept our recommendation, stating that he was willing to accept whatever risks were involved if there was a chance to be relieved of the severe, unremitting pain and to resume a normal life. Accordingly, on January 5, 1953, through a thoraco-abdominal approach the large aneurysm was excised between occluding clamps and replaced with an aortic homograft. The postoperative course was uneventful, and the patient resumed his duties as a county sheriff about one month later. He continued to work and remained in good condition until August 1962, when he began coughing up blood-stained sputum and returned to the hospital, where the diagnosis of carcinoma of the left lung was made, and on September 11, 1962, I performed left pneumonectomy. An aortogram made on this hospital admission showed the aortic homograft functioning well (Figure 15). The patient's postoperative course was satisfactory, and he again

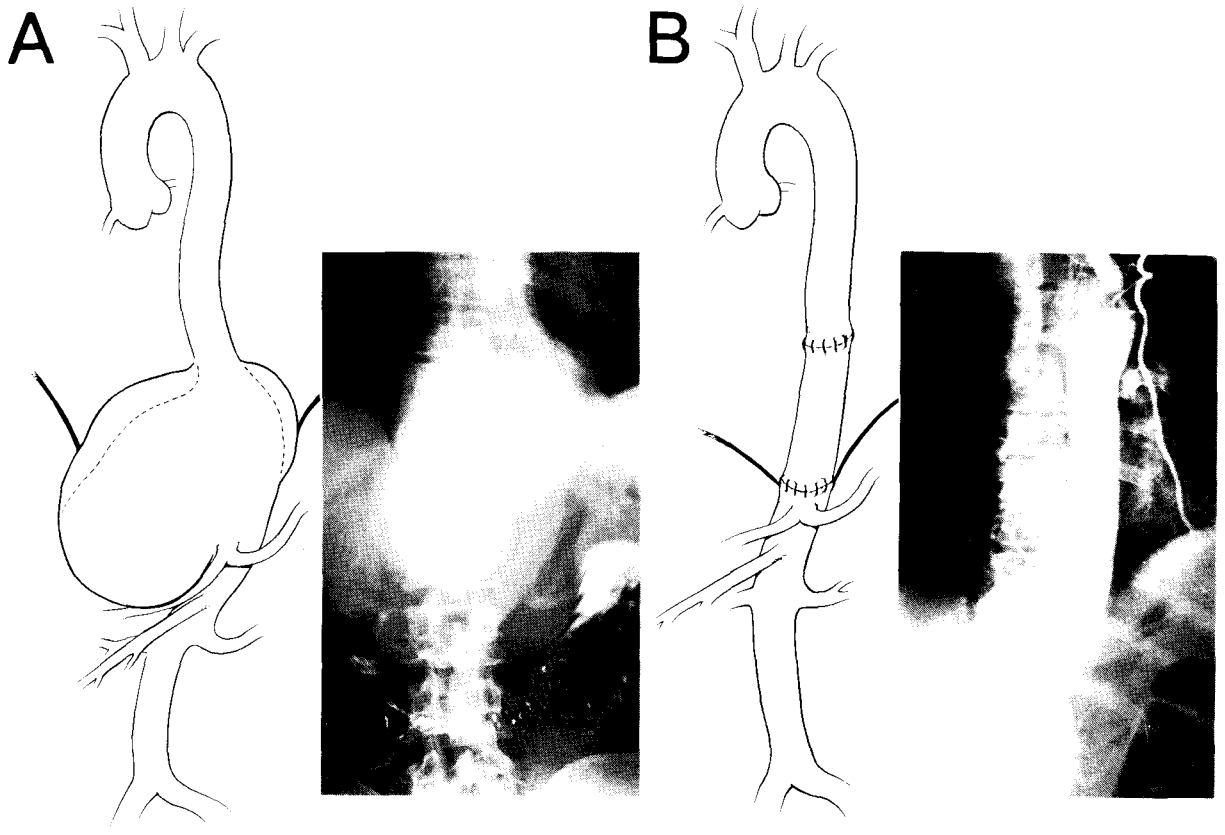


Figure 15. A, drawing and aortogram in a 46-year-old white man with severe lower back and left lower abdominal pain, showing large aneurysm of descending thoracic aorta. B, drawing showing method of resection of aneurysm and replacement with homograft; aortogram made 9 years after operation shows graft functioning well.

resumed normal activities until early 1967, when he began to manifest evidence of metastatic carcinoma, and he died suddenly on May 1, 1967.

The gratifying result obtained in this first successful case of resection of an aneurysm of the descending thoracic aorta was of considerable significance, first, in establishing the procedure as a new therapeutic method and second, in providing the assurance and encouragement to extend its application to other cases. Indeed, as further experience will show, it inaugurated a series of technical surgical developments that ultimately led to the complete surgical conquest of all aneurysms of the aorta.

An important consideration in the surgical treatment of aneurysm of the descending thoracic aorta is the potential complication of spinal cord ischemia, with resultant paresis or paralysis of the lower limbs, which may occur during the period of temporary arrest of circulation. In our early experience we used hypothermia and external shunts for this purpose. Later, we used left atrial-to-femoral-artery bypass, and still later, femoral-vein to femoral-artery bypass with oxygenator [65]. None of these methods proved effective in preventing this complication, since the incidence remained about the same with all of them, ranging between 2 and 3 per cent. Accordingly, in 1970 we abandoned all these methods and have observed no increase in the occurrence of this complication, but gratifyingly, a continued decrease in operative mortality rate to about 8 per cent. Long-term results have been highly gratifying, with some patients surviving more than twenty years after operation.

Ascending Aorta

The next most common pattern of aneurysm of the aorta is characterized by involvement of the ascending aorta. Morphologically, these aneurysms

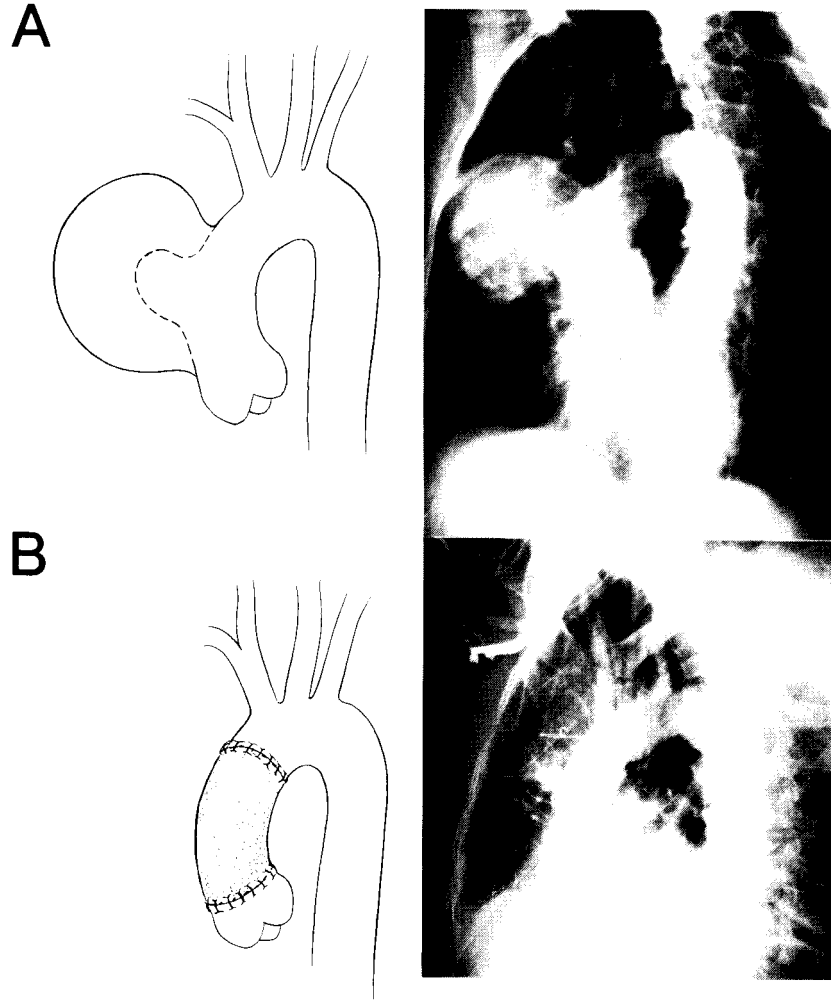


Figure 16. A, drawing and aortogram in a 50-year-old white man with increasing chest pain showing large aneurysm of ascending aorta. B, drawing showing method of resection of aneurysm and replacement with homograft; postoperative aortogram shows graft functioning well.

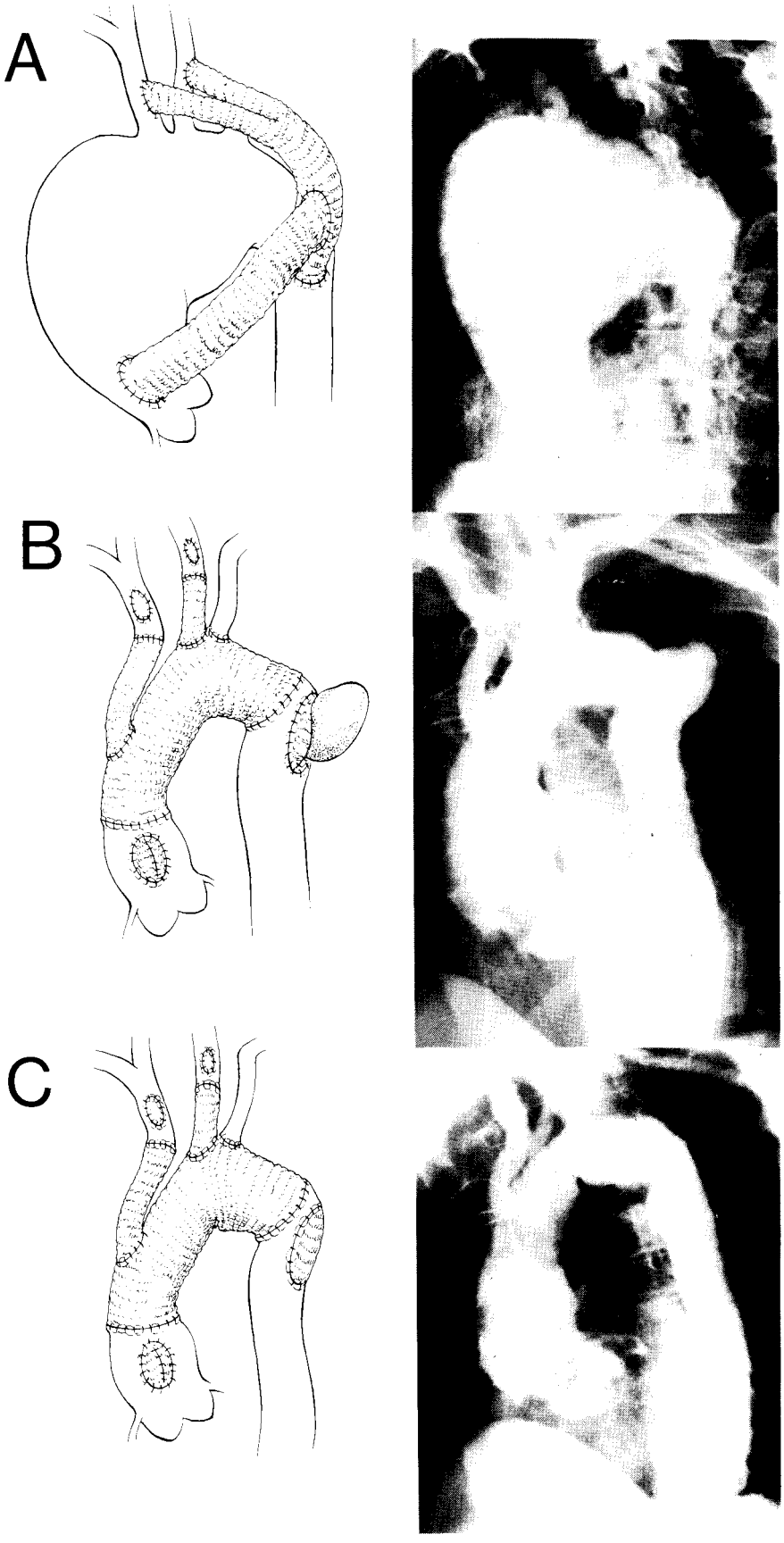


Figure 17. A, drawing and aortogram in a 44-year-old white woman complaining of chest pain showing large aneurysm of aortic arch. Drawing shows method of attaching bypass graft to maintain circulation during arrest of circulation through aortic arch. B, drawing shows graft replacement of aortic arch and proximal segments of innominate and left common carotid arteries. Drawing and aortogram made 12 years after operation show false aneurysm at site of repair after removal of temporary bypass graft to descending thoracic aorta. C, drawing shows method of repair of false aneurysm by resection and Dacron patch-graft angioplasty; postoperative aortogram shows intact and patent graft and patch-graft angioplasty.

may be sacciform or fusiform, and they may also be associated with aortic valvular disease. In occasional cases of sacciform aneurysm, tangential excision of the aneurysm with lateral aortorrhaphy or with patch-graft angioplasty may be employed [*34,66*]. In fusiform aneurysms and in more extensive sacciform aneurysms, however, this method of treatment cannot be used, and segmental resection with graft replacement is necessary. Obviously, under these circumstances, it becomes necessary to use temporary cardiopulmonary bypass.

Our first experience with this aneurysmal pattern and the first successful case of resection with graft replacement occurred in 1956 [*67,68*]. The patient, a 50-year-old white man, was admitted to the Jefferson Davis Hospital on August 18, 1956, complaining of increasing chest pain of several years' duration. Aortography confirmed the diagnosis of a large aneurysm limited to the ascending aorta (Figure 16). The patient was informed of the problem and the recommended surgical treatment of resection with graft replacement. He was also told that although we had successfully performed this operation on other segments of the aorta, we had had no experience with this method for the type of aneurysm that he had and were not aware of any other experience elsewhere. We also indicated that the risks were considerable, but that we considered the operation feasible. He accepted our recommendation, and on August 24, 1956, operation was performed (Figure 16). The aneurysm was extensive, originating just above the coronary ostia within the pericardium and involving the entire ascending aorta to the origin of the innominate artery. The patient was attached to the heart-lung machine. Because the extent of the aneurysm required the distal occluding clamp to be applied at about the origin of the innominate artery, with resultant occlusion of this vessel, a small catheter was inserted into the right common carotid artery for cerebral perfusion from the heart-lung machine

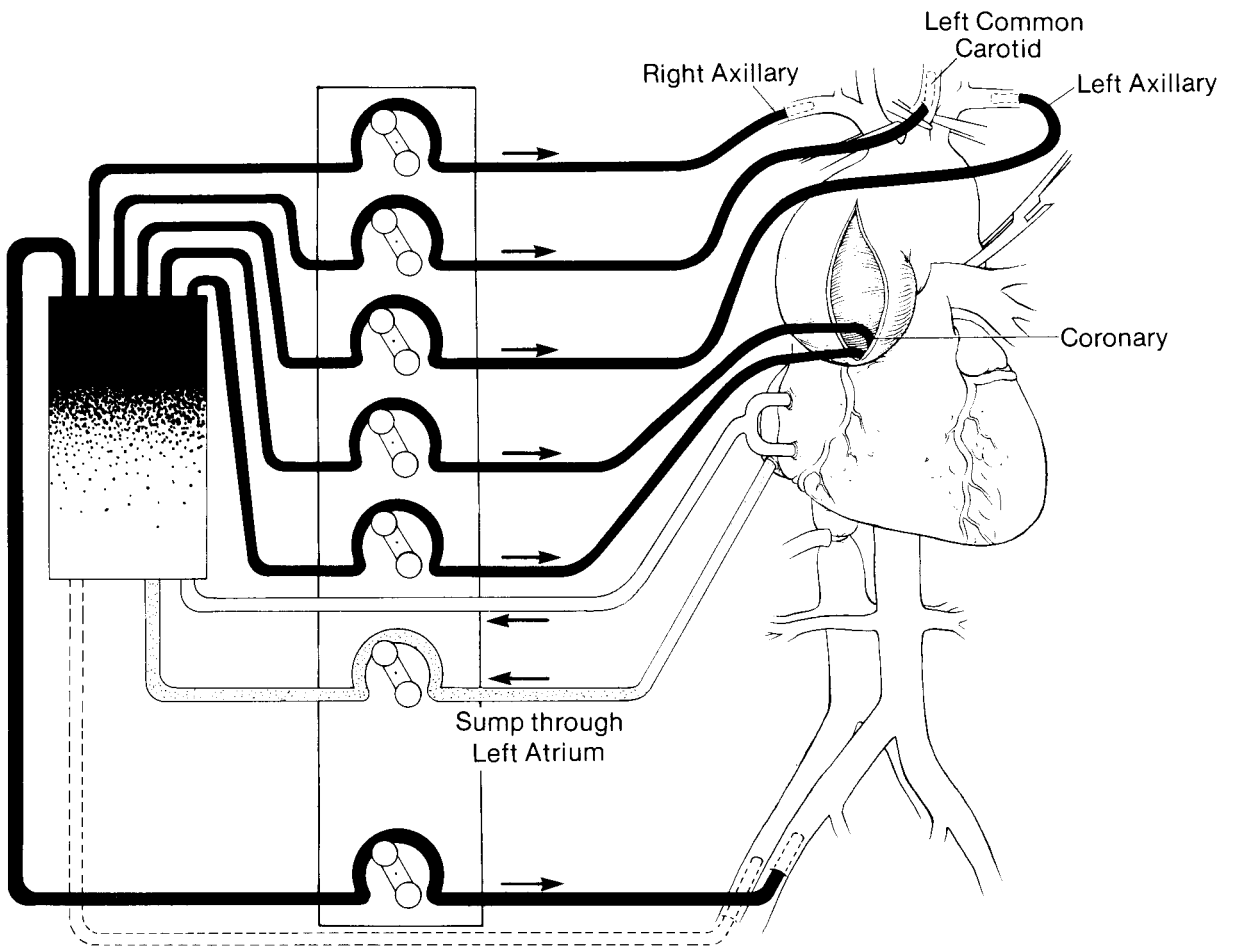


Figure 18. Drawing shows method of perfusion during cardiopulmonary bypass for resection and graft replacement of ascending aorta and aortic arch.

during occlusion of the innominate and right common carotid arteries. The aneurysm was then resected and replaced with an aortic homograft. The postoperative course was uneventful, and the patient was discharged from the hospital about three weeks later. He remained well and maintained normal activities until his death from cancer of the lung, approximately 14 years after operation.

The significance of this first successful treatment of an aneurysm in this region lies in the fact that it provided further support to the growing conviction that this method of therapy was the most effective means of treating these patients and only required the proper application of the technical resources that had now become available. The success of temporary perfusion of the carotid artery suggested that this method could be extended to permit resection of the entire aortic arch.

Entire Aortic Arch

Next in frequency of occurrence of aneurysmal patterns are those involving the entire aortic arch. The major problem involving resection of aneurysms at this site is concerned with the rapidly fatal consequences of arrest of circulation through this vital segment of the aorta on the heart and central nervous system. Our early efforts to solve this problem were directed toward use of hypothermia and temporary

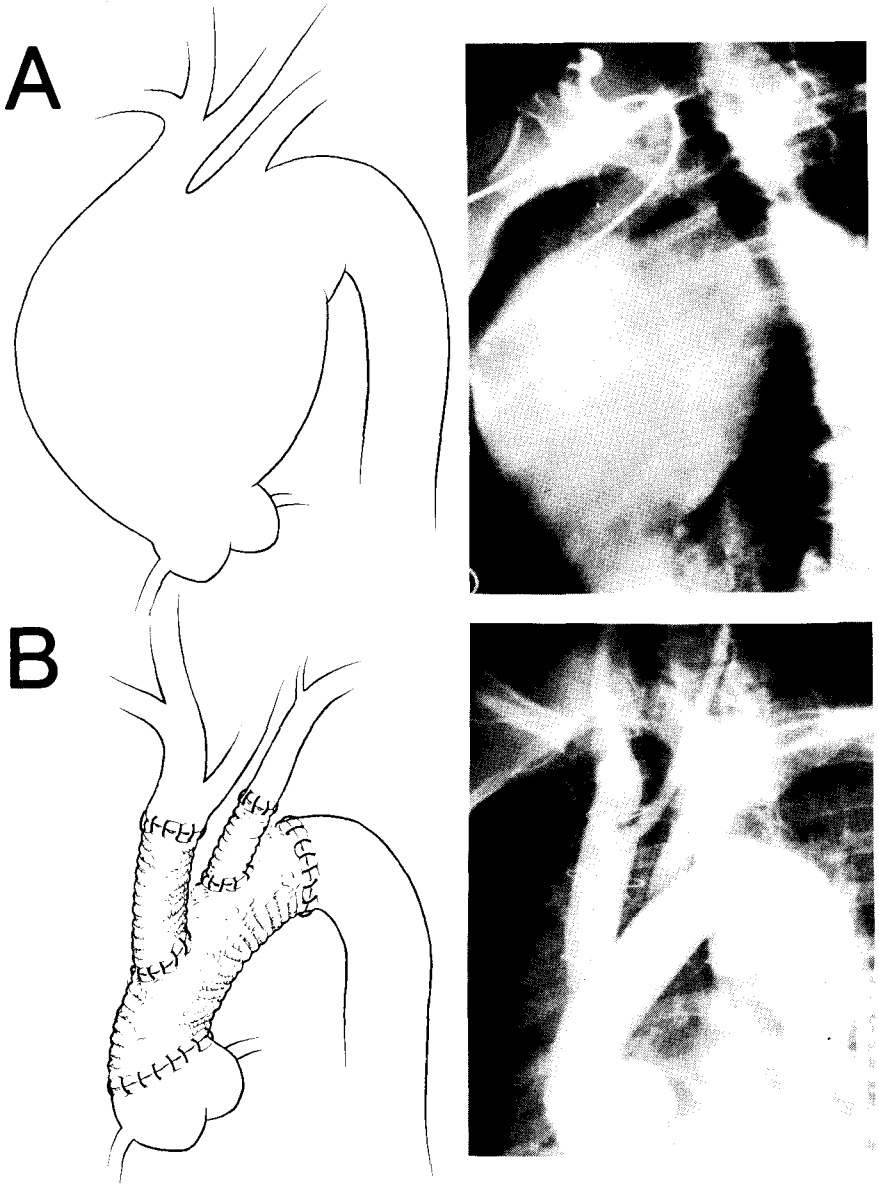


Figure 19. A, drawing and aortogram in a 58-year-old white man complaining of productive cough and pain in chest and right shoulder showing large aneurysm of ascending aorta and aortic arch. B, drawing shows method of resection of aneurysm and Dacron graft replacement, using method of perfusion shown in Figure 18; aortogram made 12 years after operation shows graft functioning well. Patient remains asymptomatic.

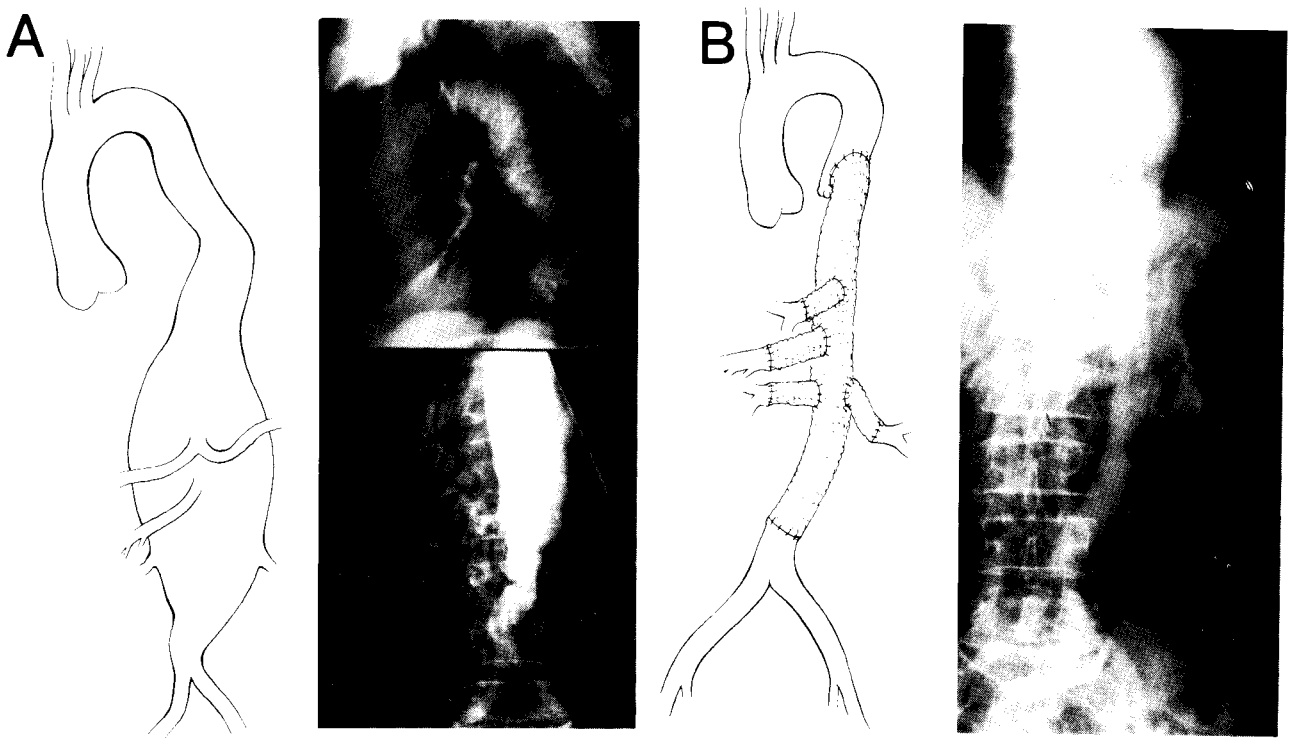


Figure 20. A, drawing and aortogram in a 65-year-old white man with subcostal pain and a pulsatile mass in upper part of abdomen, showing large fusiform aneursym arising in descending thoracic aorta and extending through diaphragm to involve most of abdominal aorta. B, drawing shows method of attaching Dacron bypass graft end-to-side to descending thoracic aorta above aneurysm and end-to-end to abdominal aorta below aneurysm, and then sequentially attaching Dacron graft to this bypass graft and to the renal arteries, superior mesenteric artery, and celiac axis after which aneurysm is removed and opening in descending thoracic aorta above the aneurysm and below the attachment of the bypass graft is closed by suture. Patient has remained well for 12 years since operation; aortogram shows the graft functioning well.

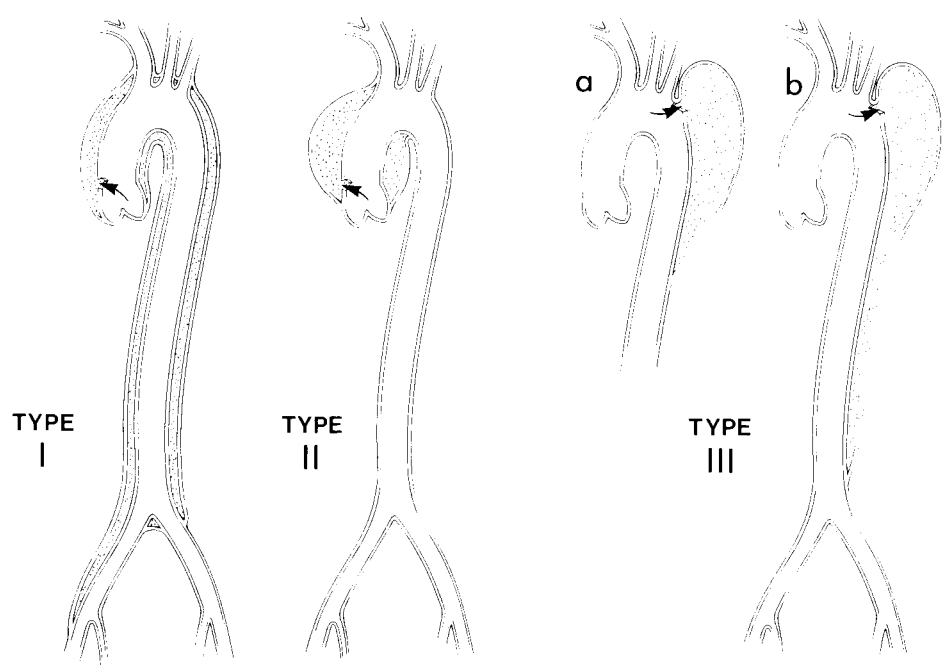


Figure 21. Drawing shows classification of dissecting aneurysms of the aorta into three basic types depending on site of origin of dissecting process and extent of dissection.

shunts to provide circulation during temporary arrest of circulation through the aortic arch [67,69]. At first, homografts and later Dacron grafts were used for this purpose with attachments of the temporary grafts to the proximal segment of the ascending aorta, to the descending thoracic aorta just distal to the left subclavian artery, and to both common carotid arteries. Clamps were then applied to arrest circulation in the aortic arch, circulation being maintained to the brain and the rest of the body through the temporary attached grafts. After the aortic arch was excised and replaced with a homograft, the temporary bypass grafts were removed. Although none of the first few patients in whom this procedure was used had long-term survival, the technical feasibility of the procedure was suggested by the extremely satisfactory immediate postoperative course of one patient who, on the ninth postoperative day, was ambulatory and taking a regular diet, but unfortunately, died two days later of a mediastinal infection. The satisfactory immediate postoperative course encouraged us to continue performing the procedure, and fortunately we achieved complete success in a subsequent case (Figure 17).

This operation, however, has certain disadvantages. For one thing, the necessity of performing and later removing four end-to-side anastomoses of the temporary shunt greatly prolongs the operative

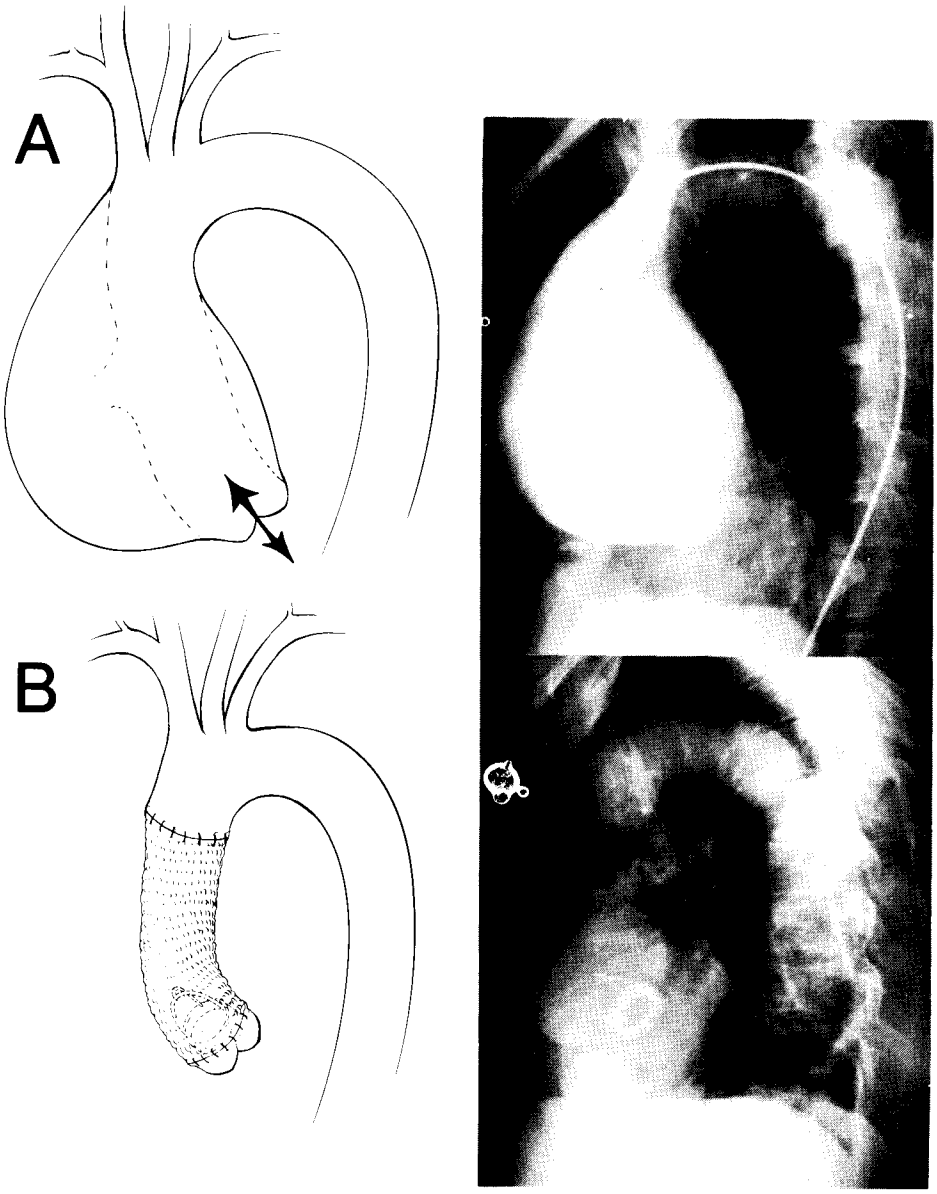


Figure 22. A, drawing and aortogram in a 42-year-old white man showing Type II dissecting aneurysm with aortic insufficiency. B, drawing shows method of resection of aneurysm of ascending aorta, replacement with Dacron graft, and aortic valve replacement. Patient has remained asymptomatic for 14 years since operation; postoperative aortogram shows well-functioning graft and replaced valve.

procedure and thus increases the risks of the operation. For another, in some patients in whom the aneurysm extends proximally to involve the entire ascending aorta, it is not possible to attach the proximal end of the shunt. Accordingly, after our successful experience with the case just described in which the entire ascending aorta was resected with temporary perfusion of the right common carotid artery, it seemed reasonable to extend this method for aneurysms of the entire aortic arch. After demonstrating its technical feasibility in the experimental laboratory, we [68] had occasion to apply it clinically for the first time in 1957. The patient, a 56-year-old white man, was admitted to The Methodist Hospital on March 12, 1957, complaining of pain in the left side of the chest. Aortography confirmed the diagnosis of a fusiform aneurysm of the entire ascending aorta and transverse arch. Exposure was obtained through a median sternotomy incision, and cardiopulmonary bypass was instituted. Through a small arteriotomy, catheters were inserted into the innominate and left common carotid arteries and connected to the heart-lung machine for temporary perfusion of these vessels. After occluding clamps were applied to isolate the ascending aorta and transverse arch, the aneurysm was excised and replaced with an aortic homograft that included the innominate and left common carotid artery branches. The immediate postoperative course was highly satisfactory, and the patient was discharged from the hospital on the sixteenth postoperative day. He resumed normal activities, and long-term follow-up continued to be satisfactory.

Subsequent experience with this procedure suggested several additional technical modifications (Figure 18). These include the use of coronary artery

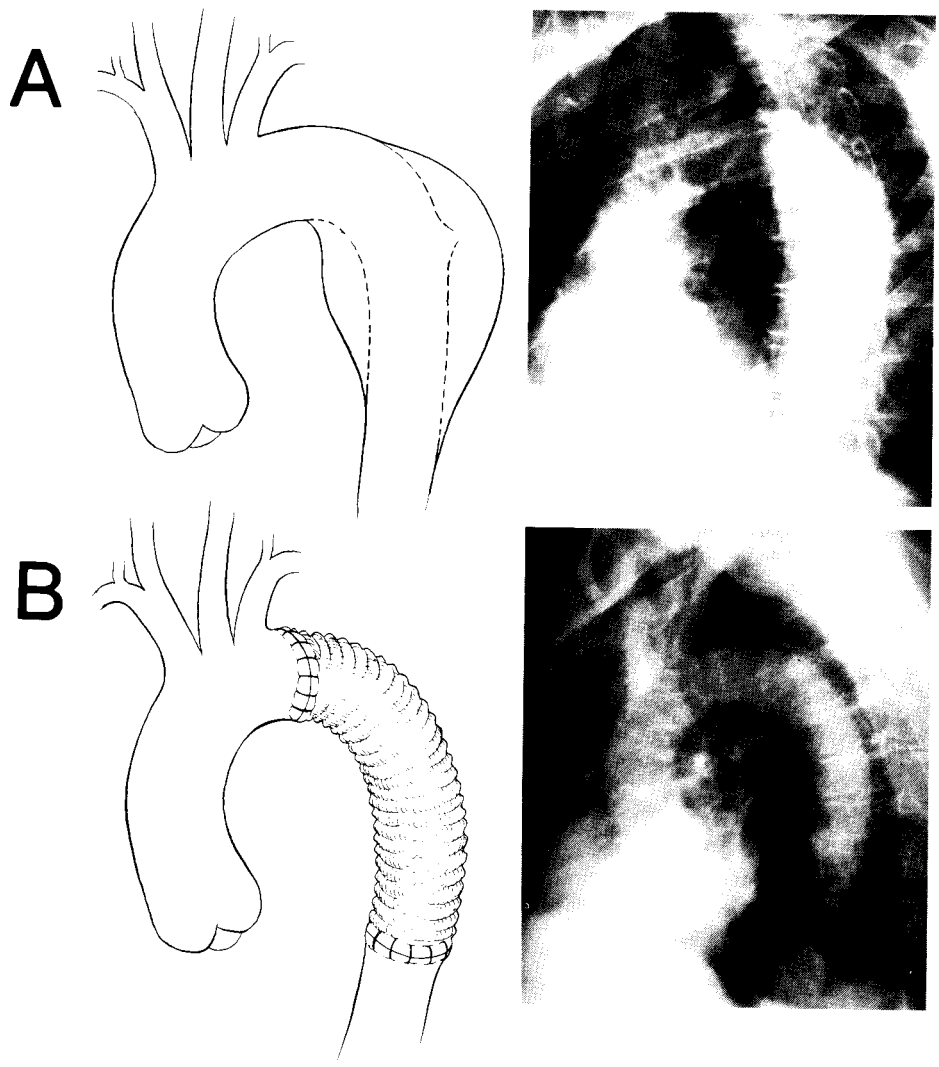


Figure 23. A, drawing and aortogram in a 60-year-old white man showing Type III dissecting aneurysm involving proximal portion of descending thoracic aorta. B, drawing shows method of resection and Dacron graft replacement. Patient has remained asymptomatic for 18 years since operation; postoperative aortogram shows graft functioning well.

perfusion and insertion of arterial perfusion catheters into both axillary arteries to provide perfusion of the vertebral arteries, since perfusion of the carotid arteries alone may not be adequate to prevent cerebral ischemia in some patients whose collateral circulation through the circle of Willis is not sufficient for this purpose. Our recent experience with this method has been most satisfactory and, of course, Dacron grafts have completely replaced the homografts used earlier (Figure 19).

Thoraco-abdominal

The next pattern of aneurysm is that referred to as thoraco-abdominal aneurysm, which arises usually in the lower descending thoracic aorta and extends down to involve the upper abdominal and sometimes

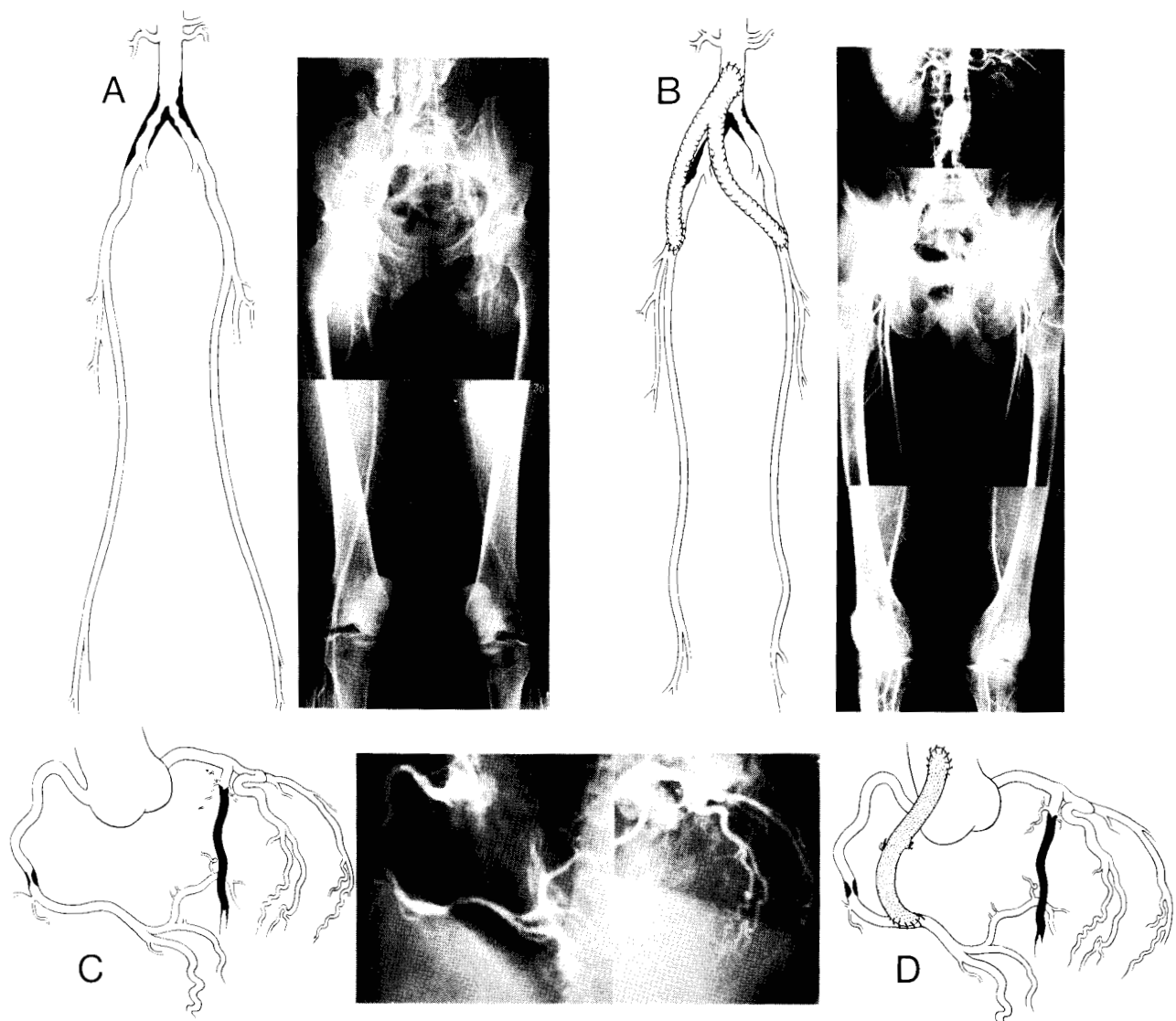


Figure 24. A, drawing and aortogram in a 45-year-old white man with intermittent claudication of lower extremities showing severe well-localized atherosclerotic occlusive disease of aorto-iliac segment. B, drawing shows method of attaching bypass graft from abdominal aorta to both common femoral arteries using Dacron bifurcation graft. Aortogram made 16 years after this operation shows graft functioning well with no recurrence of disease in this arterial bed, but patient is now complaining of severe angina. C, drawing and coronary arteriograms on this admission show severe, well-localized occlusive disease in right coronary artery and complete occlusion of left anterior descending coronary artery. D, drawing shows method of surgical treatment consisting of autogenous vein bypass graft from ascending aorta to right coronary artery. Patient has remained asymptomatic for 5 years since this operation and 21 years since first operation.

the entire abdominal aorta. The critical problem in this type of aneurysm lies in the danger of producing fatal ischemic damage to such vital structures as the liver, kidneys, and gastrointestinal tract, as a consequence of temporary arrest of circulation to these organs during the period required for resection and graft replacement. In our initial experience with this type of aneurysm, in August 1955, hypothermia was used in the attempt to prevent the potential ischemic damage to the abdominal visceral organs. This attempt, unfortunately, did not prove successful, and the patient died from these ischemic complications. In light of our previous experience with other types of aneurysm with temporary bypass grafts to provide

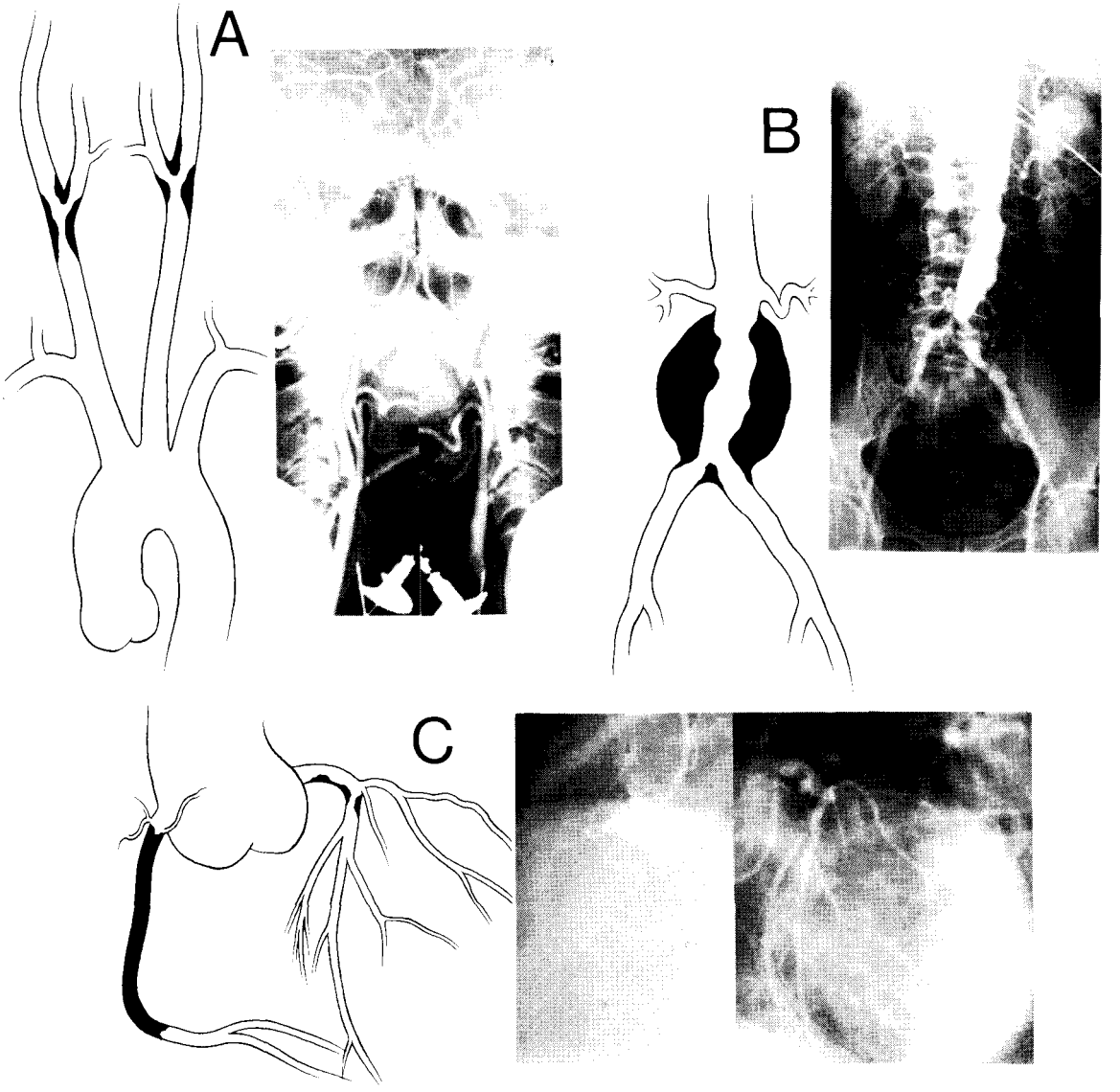


Figure 25. A, drawing and carotid arteriograms in a 54-year-old white man with manifestations of transient episodes of cerebrovascular insufficiency showing severe well-localized atherosclerotic occlusive disease at bifurcation of common carotid arteries and origin of internal carotid arteries bilaterally. Patient was successfully treated by endarterectomy and patch-graft angioplasty on both sides. B, drawing and aortogram in same patient during same admission to hospital showing aneurysm of abdominal aorta with occlusive disease of common iliac arteries, treated by resection and Dacron bifurcation graft replacement. C, drawing and coronary arteriograms in same patient 7 years later, after recent onset of severe angina, showing occlusive disease of right coronary and left anterior descending coronary arteries treated by autogenous vein bypass grafts to both of these coronary arteries. Patient remains asymptomatic 13 years after first operation on carotid arteries and aneurysm of abdominal aorta and 9 years after operation on coronary arteries.

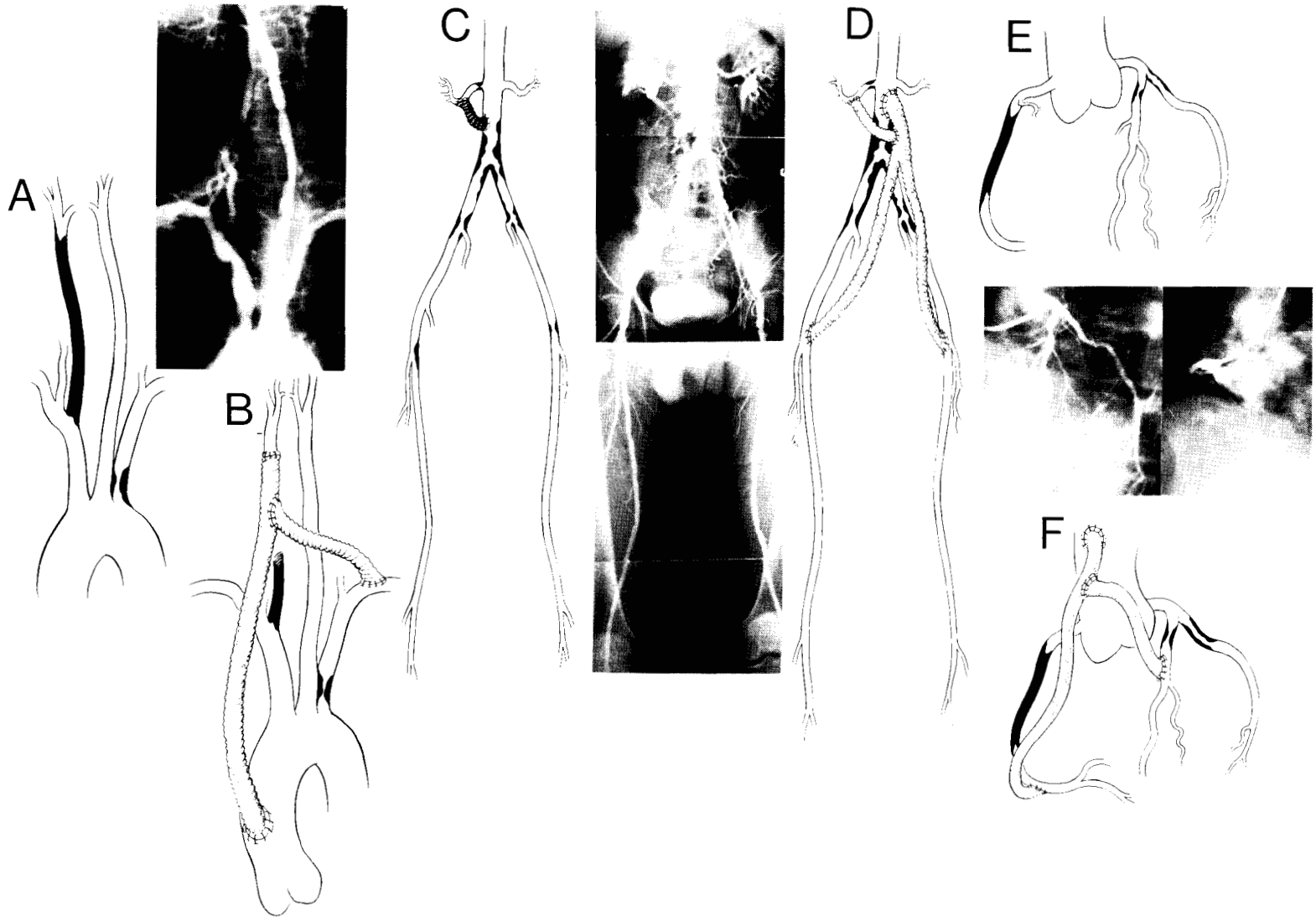


Figure 26. A, drawing and arteriogram of aortic arch in a 51-year-old white man with manifestations of cerebrovascular insufficiency, hypertension, and intermittent claudication, showing complete occlusion of right common carotid artery and left subclavian artery. B, drawing showing method of surgical treatment consisting of Dacron bypass graft from ascending aorta to right common carotid artery and left subclavian artery. C, drawing and abdominal aortogram in same patient on readmission to hospital 3 months later, showing severe stenosis of left renal artery, occluded bypass graft to left renal artery previously performed elsewhere, and severe occlusive disease of aorto-iliac segment. D, drawing showing method of surgical treatment consisting of Dacron bypass graft from abdominal aorta to both common femoral arteries and to left renal artery. E, drawing and coronary arteriograms in same patient with recent onset of severe angina following admission to hospital 3 years later, showing complete occlusion of right and left anterior descending coronary arteries. F, drawing showing method of surgical treatment consisting of autogenous vein bypass to right coronary and left anterior descending coronary artery. Patient remains asymptomatic 6 years after first two operations and 3 years after third operation.

circulation during arrest of circulation in the aorta in patients with other types of aneurysm, we decided to use this principle in the next patient on whom operation was performed on October 19, 1955, a 65-year-old white man [*70*]. By this means, it was possible to minimize the ischemic period to the vital organs during resection and graft replacement with anastomosis of branches of the graft to the celiac, superior mesenteric, and both renal arteries, and after completion of the procedure the temporary bypass graft was removed. The highly gratifying immediate and long-term results in this patient provided us with the conviction that this was the preferable method of surgical treatment for this type of aneurysm. Subsequent experience led to a modification of the procedure that proved to be of great advantage. This modification consisted in combining the bypass principle with a permanent replacement [*71*] (Figure 20). Thus, by attaching a Dacron graft to the descending thoracic aorta just above the an-

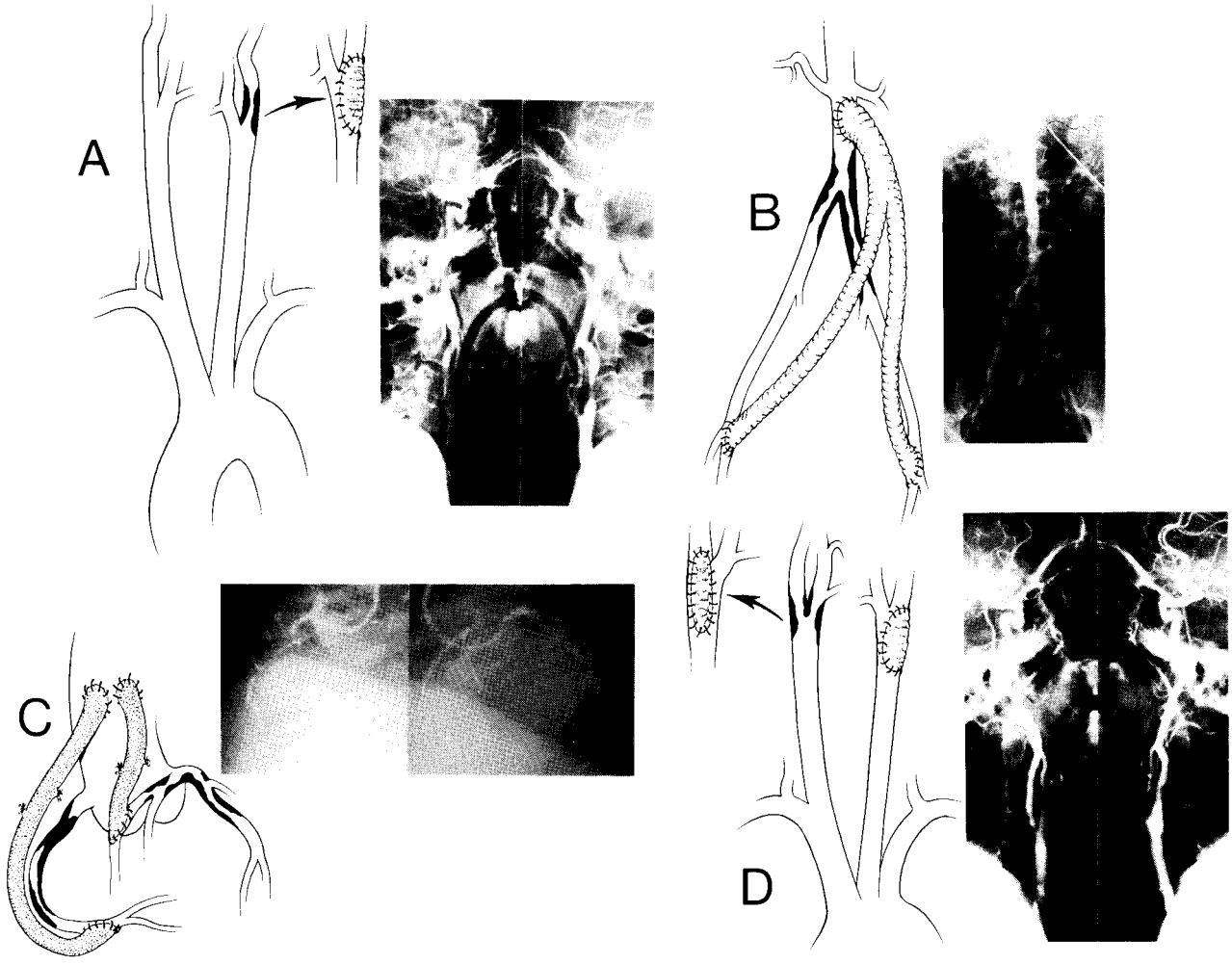


Figure 27. A, drawing and carotid arteriograms in a 50-year-old white man with manifestations of transient cerebrovascular insufficiency and intermittent claudication of lower limbs showing severe, well-localized occlusive disease at bifurcation of left common carotid artery and origin of internal carotid artery which was treated by endarterectomy and patch-graft angioplasty. B, drawing and abdominal aortogram in same patient on readmission to hospital 4 months later showing severe occlusive disease of aorto-iliac segment treated by Dacron bypass graft from abdominal aorta to both common femoral arteries. C, drawing and coronary arteriograms in same patient with recent onset of progressively severe angina, on readmission to hospital five years later, showing severe occlusive disease in right and left anterior descending coronary arteries as well as in circumflex branch. Treatment consisted in autogenous vein bypass to right and left anterior descending coronary arteries. The circumflex coronary artery was found not suitable for bypass. D, drawing and carotid arteriograms in same patient 7 years later showing severe stenosis of right carotid artery which was treated by endarterectomy and patch-graft angioplasty. Patient has remained asymptomatic for almost 15 years since original operation.

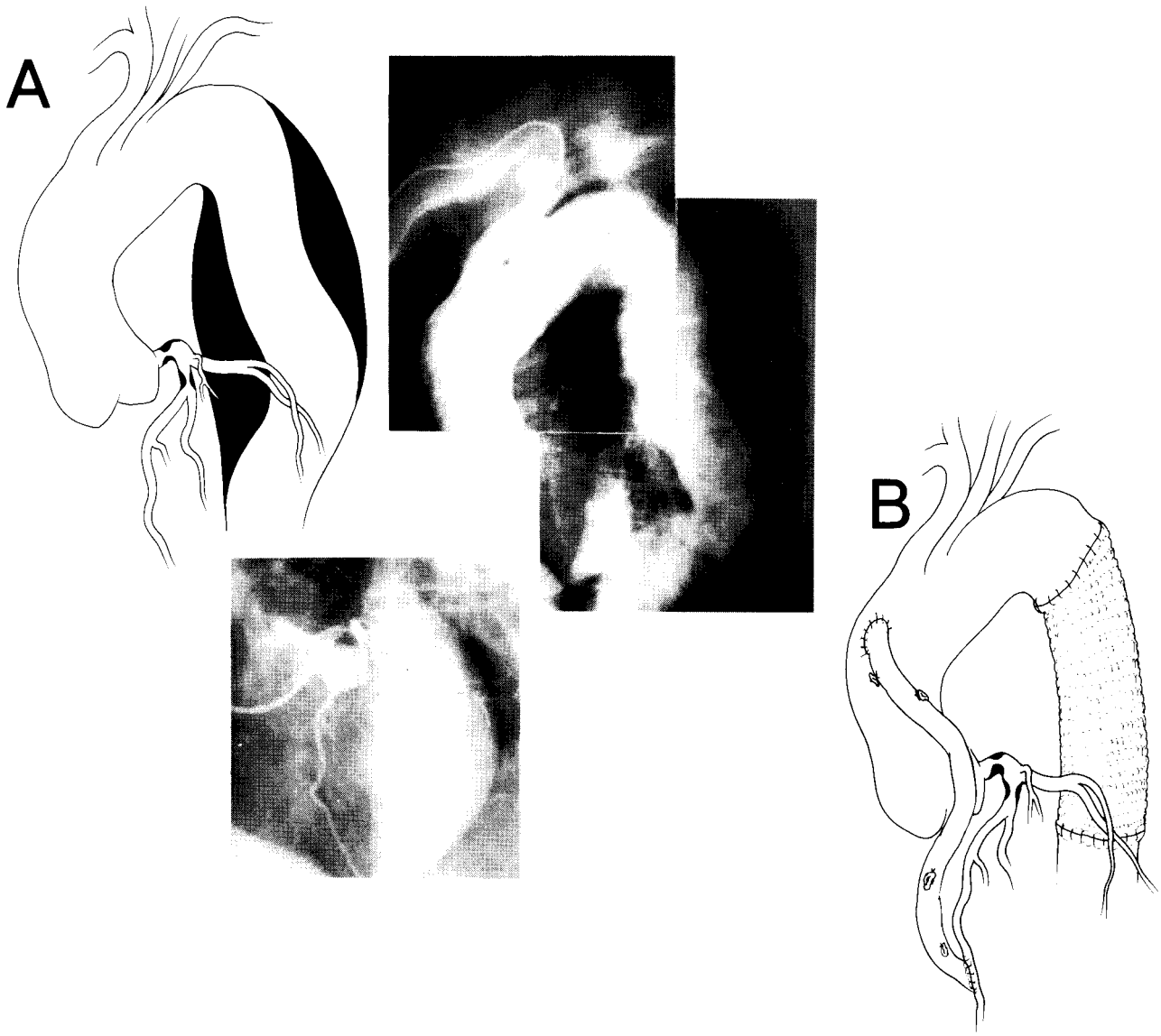


Figure 28. A, drawing and thoracic aortogram and coronary arteriogram in a 57-year-old white man with severe angina showing occlusive disease of left coronary and anterior descending branch and fusiform aneurysm of descending thoracic aorta. B, drawing showing method of surgical treatment consisting in autogenous vein bypass graft to left anterior descending coronary artery and, in a second-stage operation 2½ weeks later, resection and Dacron graft replacement of aneurysm of descending thoracic aorta. Patient has remained asymptomatic for 7 years since operation.

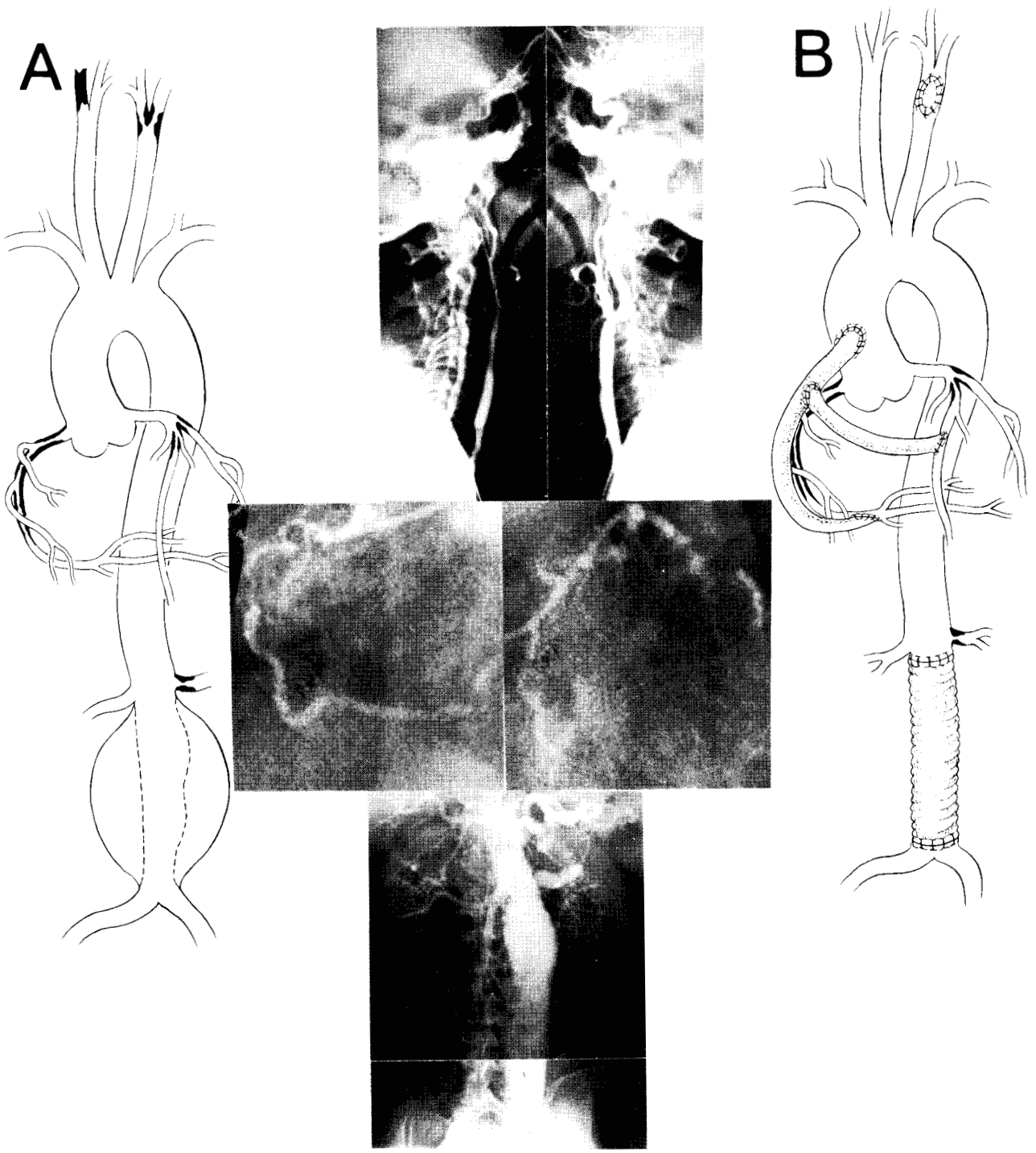


Figure 29. A, drawing and arteriograms of carotid and coronary arteries and abdominal aorta in a 51-year-old white man with manifestations of cerebrovascular insufficiency, angina, and tender pulsatile mass in abdomen showing complete occlusion of right internal carotid artery, severe stenosis at bifurcation of left common carotid and origin of internal carotid arteries, occlusive disease of right coronary and left anterior descending arteries, and aneurysm of abdominal aorta. B, drawing showing method of surgical treatment consisting in endarterectomy and patch-graft angioplasty of left carotid artery lesion, autogenous vein bypass to right coronary and left anterior descending coronary arteries, and resection and Dacron graft replacement of aneurysm of abdominal aorta. Patient remains asymptomatic 8 years after operation.

eurysm and to the abdominal aorta below the aneurysm, we could maintain the circulation in each major visceral branch while sequentially attaching Dacron grafts from the major bypass graft to one renal artery and then the other, followed by attachment of similar grafts to the superior mesenteric and celiac axis, and then resection of the aneurysm and suturing of the ends of the aorta. The period of ischemic arrest in each of these arteries can thus be minimized to about 10 or 12 minutes, a period which is well tolerated.

Dissecting Aortic Aneurysms

Dissecting aneurysm of the aorta was one of the most challenging problems we have encountered for a number of reasons. For one thing, it had long been recognized as a highly fatal disease, most patients dying within a few days to a few months after onset of the disease. For another, unlike sacciform and fusiform aneurysms, which tend to be localized, dissecting aneurysms may extend throughout the aorta, often arising in the upper reaches of the aorta. Our initial experience with this problem and the first successful case of dissecting aneurysm treated by resection occurred in a 58-year-old white man who had what we subsequently described as Type III [72]. At operation on July 7, 1954, the aneurysm in the descending thoracic aorta was U-shaped, and after occluding clamps had been applied above and below the U-shaped segment, it was resected; the lumen above and a double lumen in the distal end were normal. It was then reasoned that by suturing the edges of the aortic wall forming the false lumen, it would be possible to obliterate the opening of the false lumen and thus restore circulation into the normal lumen. After this procedure was completed, the upper end of the normal aorta was attached by end-to-end anastomosis to the normal lumen of the distal end. The highly gratifying immediate and subsequent course of the patient provided great en-

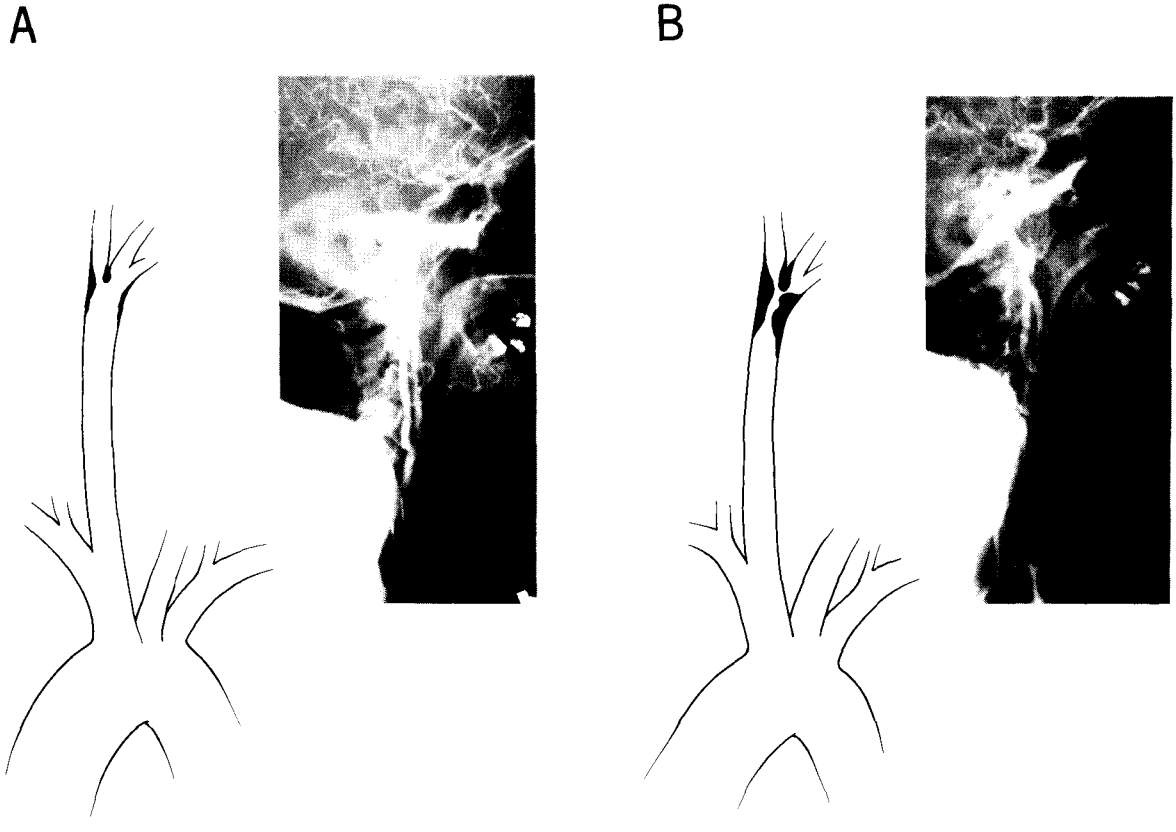


Figure 30. A, drawing and right carotid arteriogram in a 59-year-old white man with mild manifestations of cerebrovascular insufficiency showing mild occlusive disease at bifurcation of right carotid artery. B, drawing and right carotid arteriogram in same patient 3 years later, with moderate to severe manifestations of cerebrovascular insufficiency, showing severe occlusive disease at bifurcation of right common carotid artery and origin of internal carotid artery treated by endarterectomy and patch-graft angioplasty; patient has remained asymptomatic for past 6 years since operation.

couragement to pursue this method of treatment, and in the next few cases, grafts were used to replace the defect after excision of the aneurysm and suture-closure of the distal false lumen.

With increasing experience and analysis of the anatomicopathologic features of the disease, we were able to classify the disease into three types [73] (Figure 21). In Type I, the dissecting process begins in the ascending aorta and extends for varying distances throughout the aorta. Surgical treatment in this type, which is indicated in the presence of progression with imminent rupture, consists essentially in primary repair with obliteration of the false lumen or with graft replacement. In Type II, the dissecting process is limited to the ascending aorta, and surgical treatment consists in resection with graft replacement. Aortic valvular replacement may also be required, since aortic insufficiency is often associated with this type (Figure 22). In Type III, the dissecting process arises in the descending thoracic aorta, usually just distal to the origin of the left subclavian artery and extends down for varying distances in the descending thoracic and abdominal aorta. Fortunately, in most cases, the false lumen near the diaphragm is small. Surgical treatment consists essentially in resection with graft replacement, as previously described (Figure 23). Results of operation have proved highly gratifying, with good long-term results,

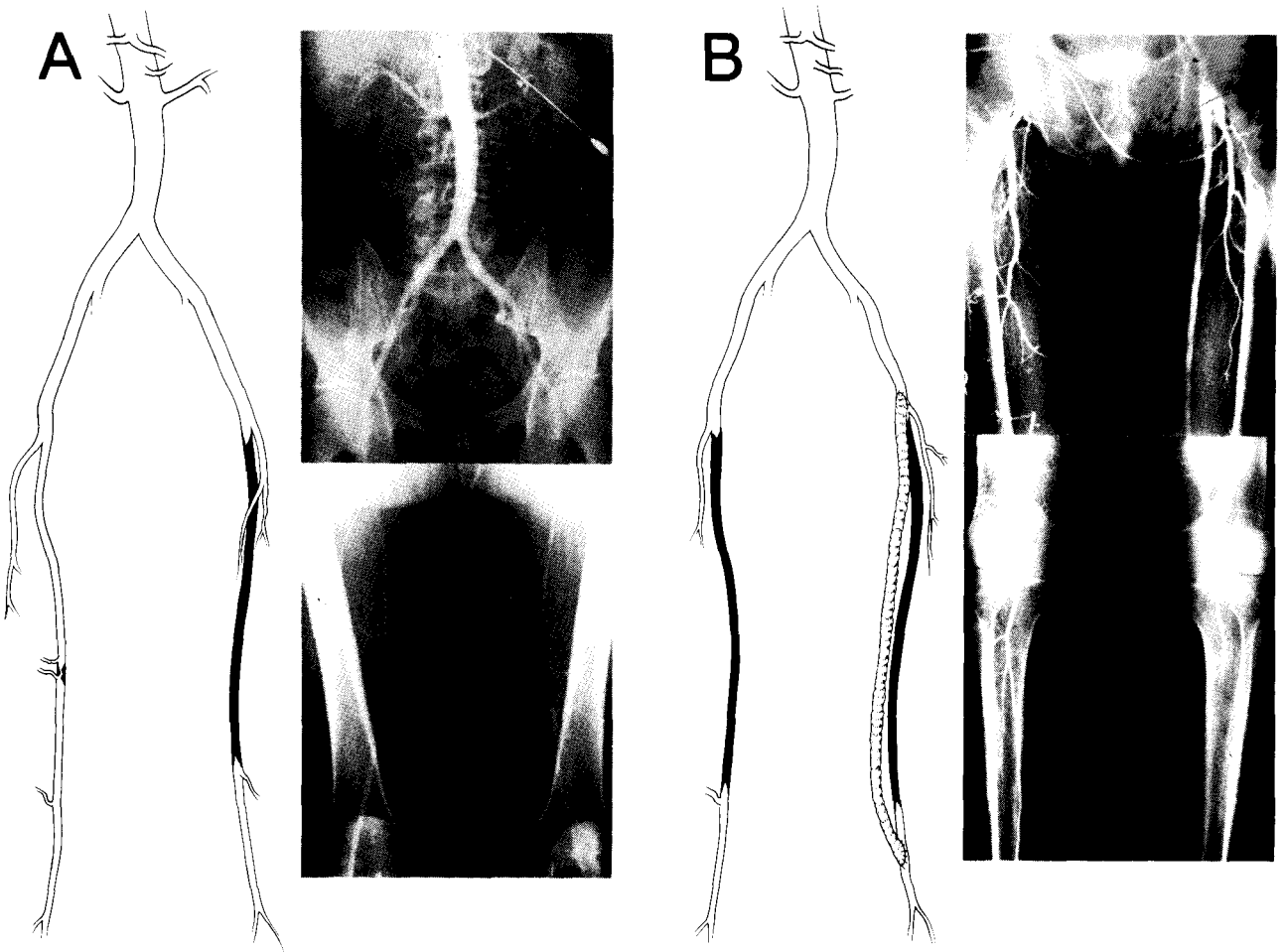


Figure 31. A, drawing and aortogram in a 68-year-old white man with intermittent claudication of left lower extremity showing localized complete occlusion in left superficial femoral artery treated by Dacron femoropopliteal bypass graft. Note mild, short, stenotic lesion in right superficial femoral artery. B, drawing and aortogram in same patient admitted to hospital one year later with recent onset of intermittent claudication of right lower extremity now showing good function of left femoropopliteal bypass graft but complete occlusion of proximal two-thirds of right superficial femoral artery. Patient was treated by right Dacron femoropopliteal bypass graft with complete relief of symptoms.

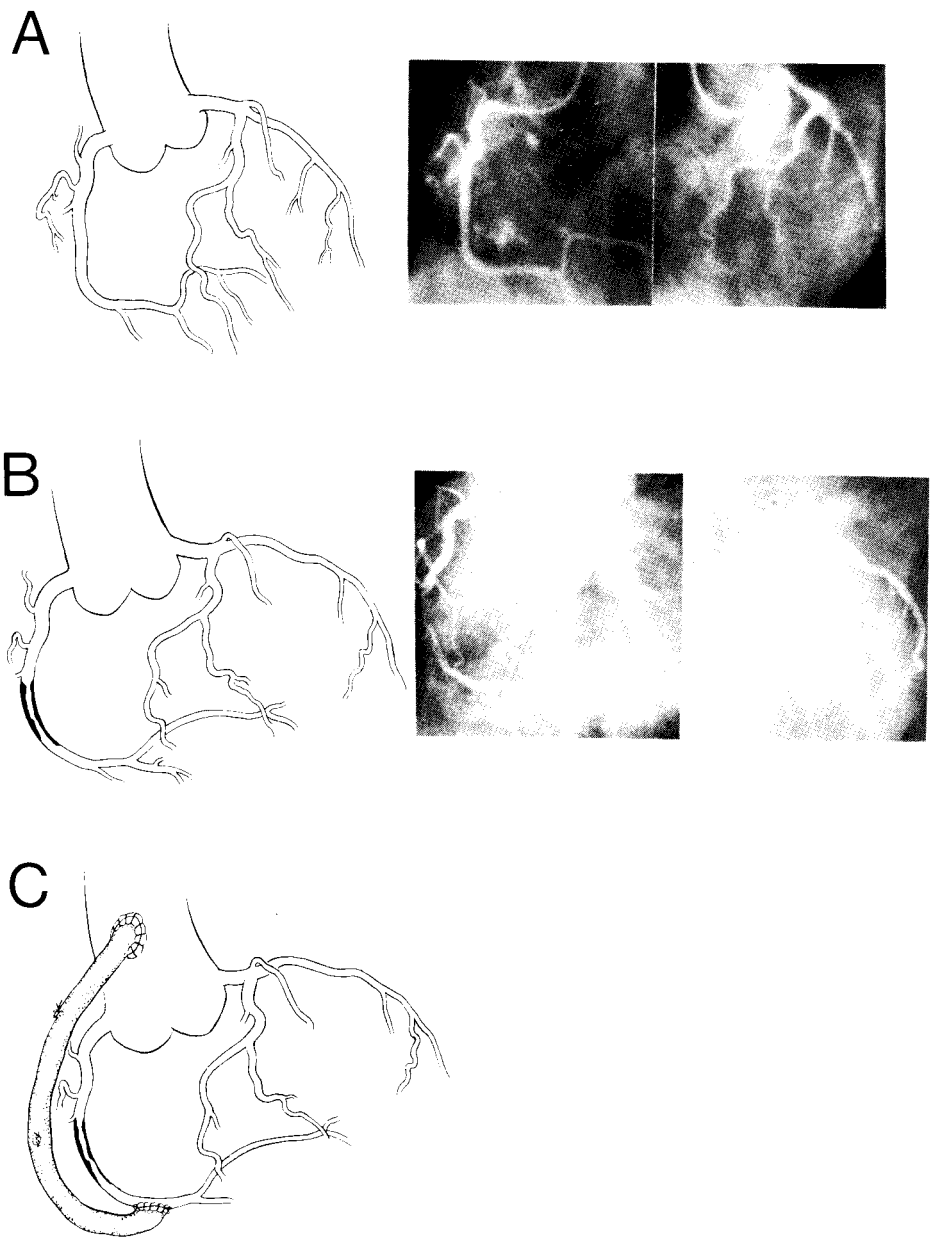
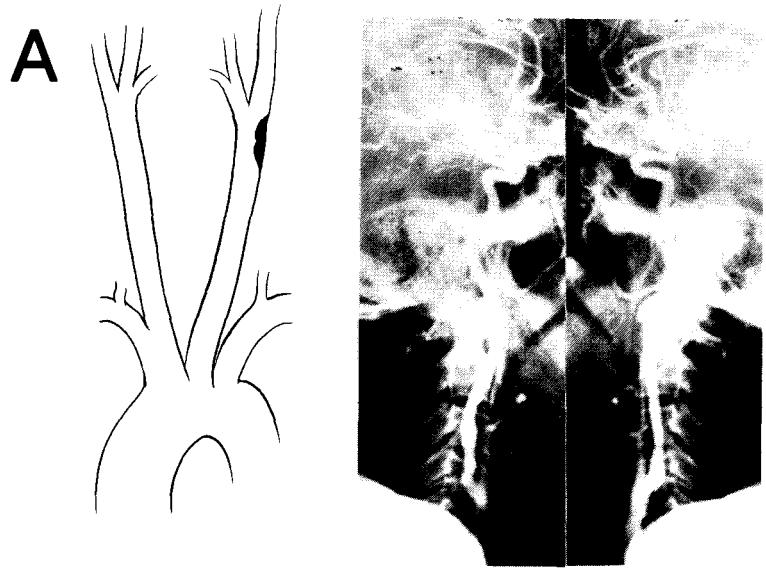


Figure 32. A, drawing and coronary arteriograms in a 51-year-old white woman with some thoracic discomfort suggesting angina showing relatively normal coronary arteries. B, drawing and coronary arteriograms in same patient readmitted to hospital 3 years later with severe angina showing severe, well-localized occlusive disease in midportion of right coronary artery. C, drawing showing method of surgical treatment consisting in autogenous vein bypass graft to right coronary artery. Patient has remained asymptomatic for 2 years since operation.



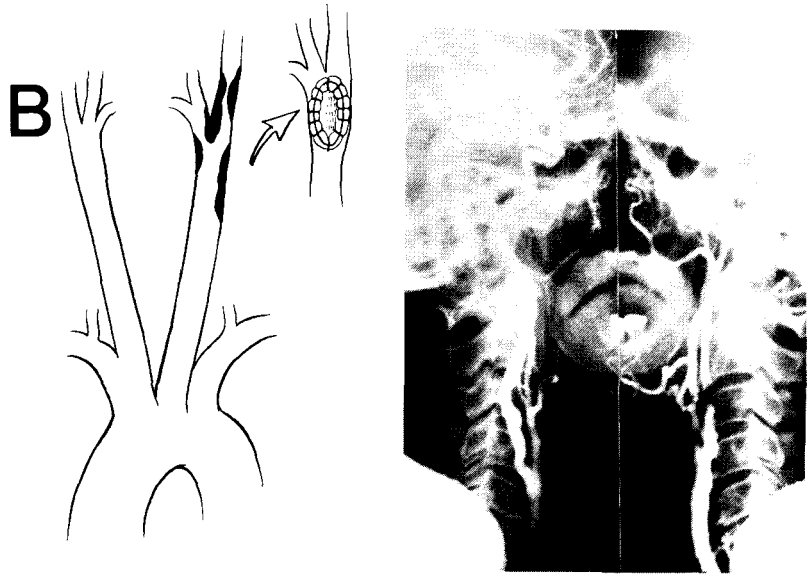


Figure 33. A, drawing and carotid arteriograms in a 56-year-old white man with intermittent claudication of lower extremities and murmur over left carotid artery showing mild atherosclerotic disease without stenosis in carotid arteries. Patient had severe aorto-iliac occlusive disease and was treated by means of a bypass graft from the abdominal aorta to both external iliac arteries with complete relief of symptoms. B, drawing and carotid arteriograms in same patient, with recent onset of manifestations of cerebrovascular insufficiency on readmission to hospital 6 years later, showing severe occlusive disease of left internal carotid artery which was treated by endarterectomy and patch-graft angioplasty. Patient has remained well for 6 years since this operation.

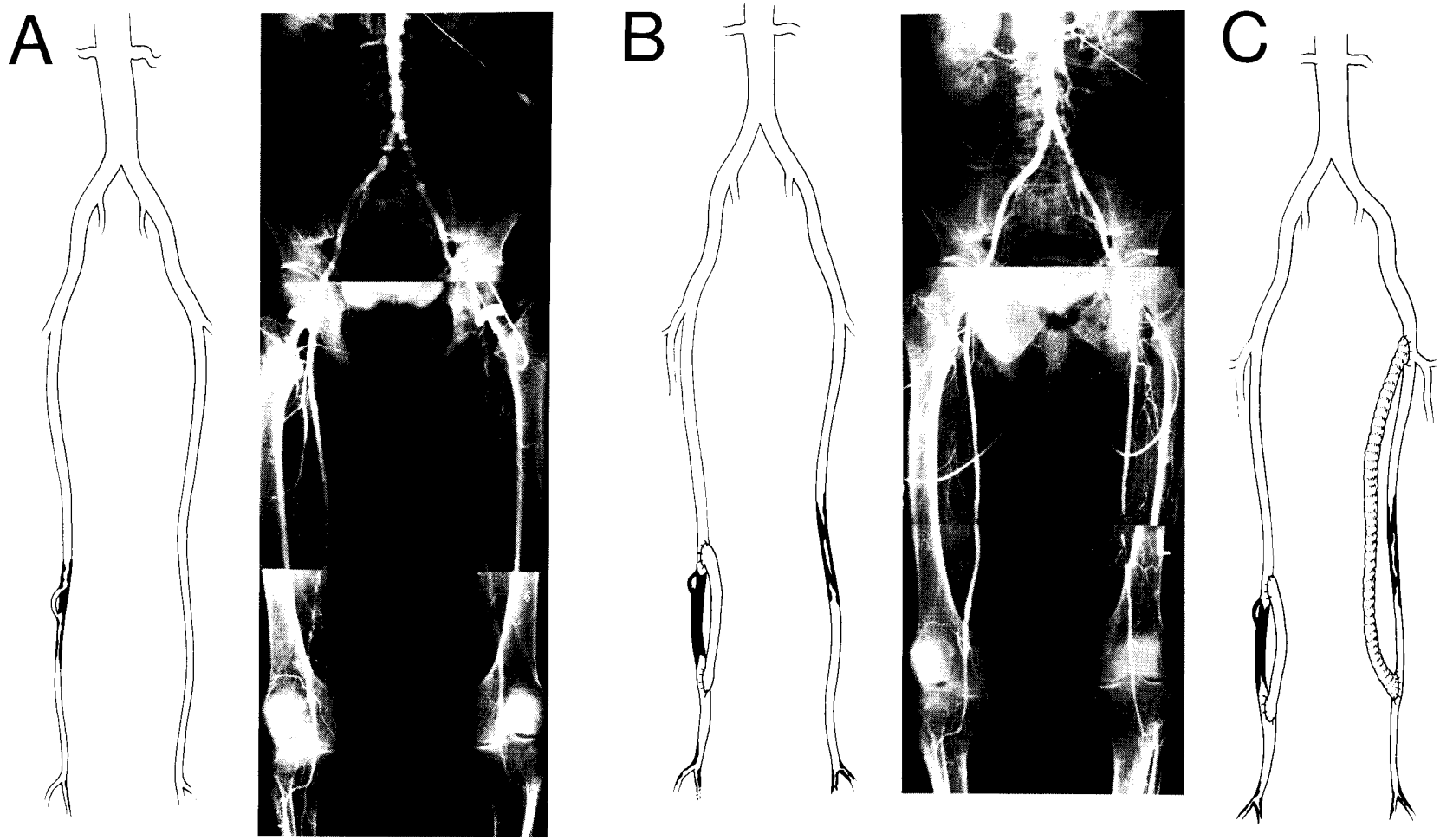


Figure 34. A, drawing and abdominal aortogram in a 61-year-old white man with severe intermittent claudication of left lower extremity showing well-localized occlusive disease in distal portion of right superficial femoral artery and in right popliteal artery treated by autogenous-vein bypass graft. Patient had no significant disease in left superficial femoral artery at this time and had pedal pulses on this side. B, drawing and aortogram in same patient with recent onset of intermittent claudication in left lower limb on readmission to hospital 8 years later, now showing well-localized complete occlusive disease in left superficial femoral artery. Note that bypass graft on right side is functioning well. C, drawing shows method of surgical treatment consisting in left Dacron femoropopliteal bypass graft. Patient has remained relatively asymptomatic for 5 years since last operation.

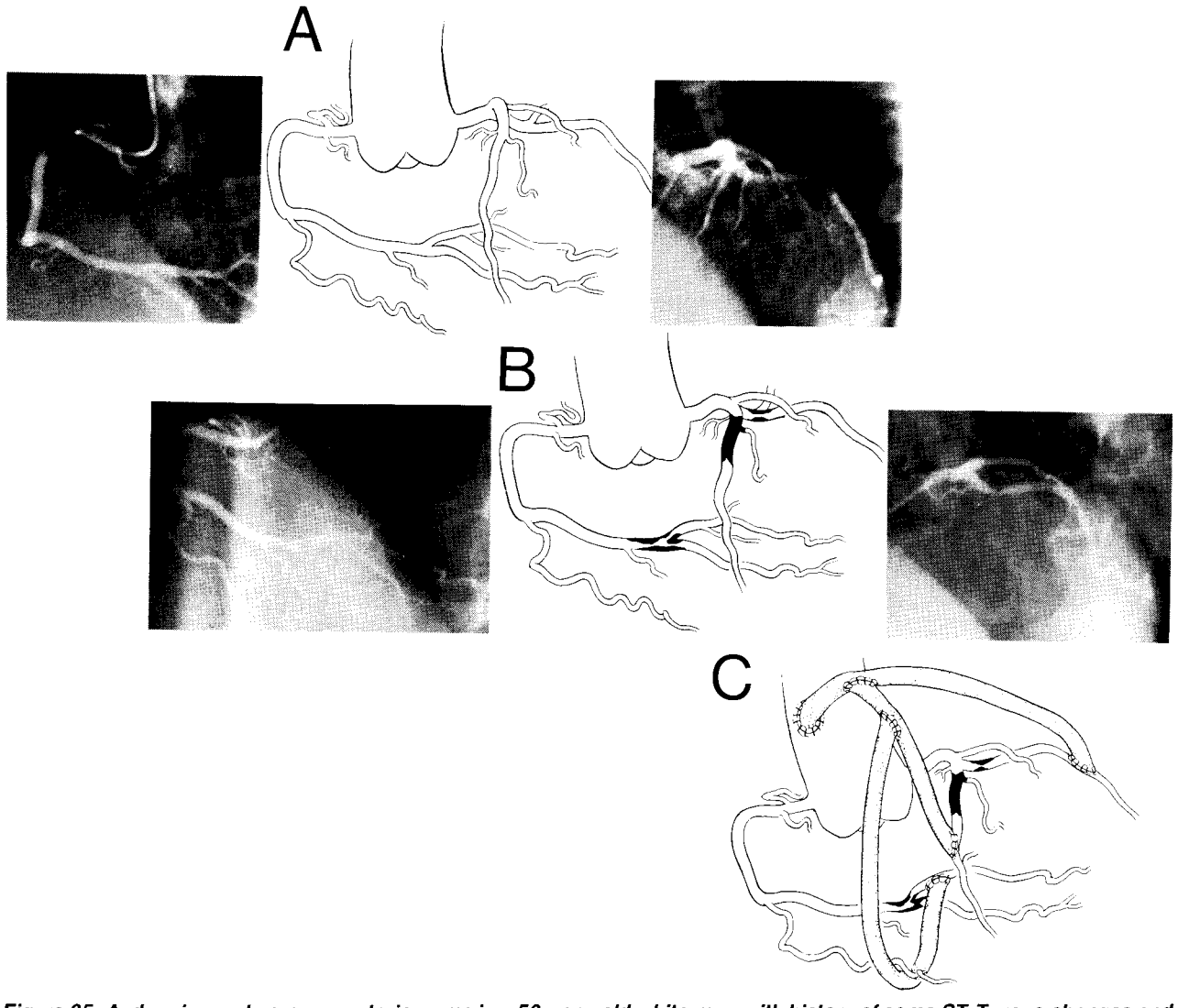


Figure 35. A, drawing and coronary arteriograms in a 50-year-old white man with history of some ST-T wave changes and QT prolongation after an emergency cholecystectomy, with positive stress test showing no stenotic lesions and only some mild plaque formation. B, drawing and coronary arteriograms in same patient 7 years later with progressively severe angina during past year, now showing severe stenotic occlusive disease in distal portion of right coronary artery, complete occlusion of proximal segment of left anterior descending artery, and severe, localized stenotic lesion in proximal segment of circumflex coronary artery. C, drawing shows method of surgical treatment consisting in autogenous-vein bypass graft to posterior descending branch of right, left anterior descending, and circumflex coronary arteries. Patient has remained asymptomatic for 2 years since operation.

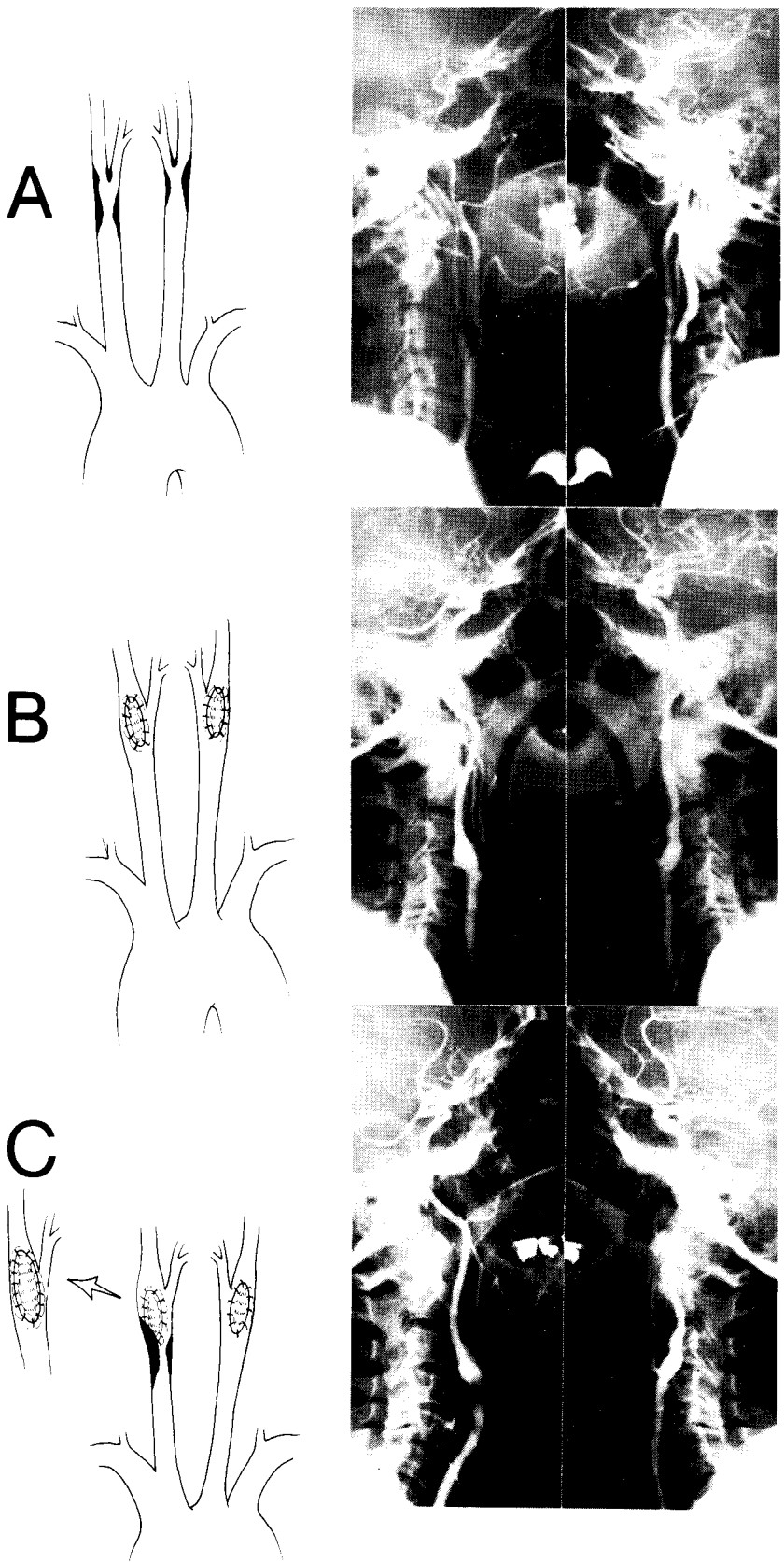


Figure 36. A, drawing and carotid arteriograms in a 54-year-old white man with manifestations of cerebrovascular insufficiency, showing severe well-localized atherosclerotic occlusive disease at bifurcation of both common carotid arteries treated by endarterectomy and patch-graft angioplasty. B, drawing and carotid arteriograms in same patient made 11 years after operation shows no evidence of recurrent disease. Patient was asymptomatic at this time. C, drawing and carotid arteriogram in same patient 6 years later, and 17 years after first operation, with recent onset of transient ischemic episodes of cerebrovascular insufficiency, now showing significant well-localized atherosclerotic occlusive disease in right common carotid artery just below previous endarterectomy. This was treated by endarterectomy and patch-graft angioplasty. Patient has remained asymptomatic for 2 years since this operation.

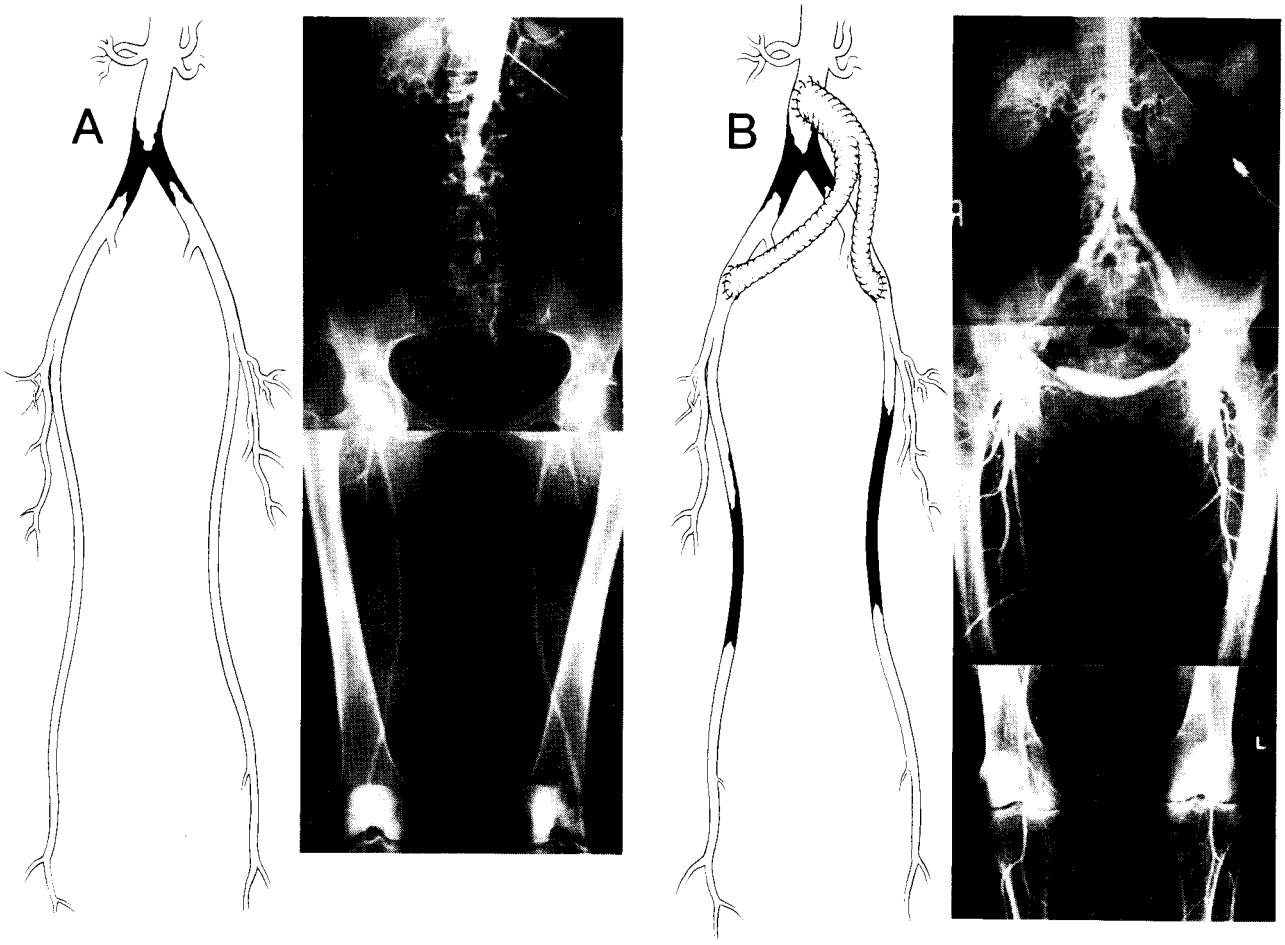


Figure 37. A, drawing and abdominal aortogram in a 57-year-old white man with intermittent claudication of lower limbs, showing well-localized complete occlusive disease involving aorto-iliac segment, treated by Dacron bypass graft from abdominal aorta to both external iliac arteries. Note there is no evidence of atherosclerotic occlusive disease in superficial femoral or popliteal arteries. B, drawing and aortogram in same patient 13 years later. Intermittent claudication had developed during past year. Aortogram shows complete occlusive disease involving proximal portions of both superficial femoral arteries. Treatment consisted of Dacron femoropopliteal bypass grafts bilaterally. Patient has remained asymptomatic for 2 years since this operation.

as evidenced by survival of some patients for more than twenty years.

Combined Aneurysmal and Occlusive Disease

Finally, certain combined patterns of disease involving both aneurysms and occlusive lesions in the various categories of arterial beds described may occur in the same patient simultaneously, or they may develop sequentially (Figures 24–29). Some patients, for example, may have occlusive lesions in the coronary and carotid arteries and an aneurysm of the abdominal or thoracic aorta. Other patients may have occlusive disease of the major branches of the aortic arch and the terminal abdominal aorta and its major branches. A number of variations in these combined patterns of aneurysmal and occlusive disease have been observed; this emphasizes the need for careful clinical assessment of the patient whose complaint may be related to one arterial bed but who may have significant lesions in other arterial beds. Obviously, if clinical manifestations suggest this possibility, appropriate arteriographic studies are indicated to delineate precisely the extent of involvement. Some judgment must then be exercised in determining the need for surgical treatment as well as the priority in its application.

The sequential occurrence of these different patterns of arterial disease is also of considerable interest. In some patients, for example, after appropriate treatment of occlusive disease in one arterial bed, the patient may remain asymptomatic for some time and later the disease develops in another arterial bed, although there may be no further progression of the disease in the originally involved arterial bed (Figures 24, 27). Thus, significant arterial and occlusive lesions may develop in several arterial beds over a period of ten to twenty years.

Rate of Progression of Occlusive Disease

The rate of progression of atherosclerotic occlusive disease is another important observation, since it constitutes the most important factor influencing prognosis. On the basis of analysis of our long-term follow-up studies, we [38] have classified these different rates of progression into three groups. In Group I the rate of progression is rapid, usually within one to three years. In these patients the atheromatous process, when first observed, is clinically and arteriographically insignificant, but within a few years it becomes clinically significant, with arteriographic evidence of severe stenosis (Figures 30–32). In Group II the rate of progression is moderate, usually over a period of five to eight years (Figures 33–35). In Group III the rate of progression is slow, usually over a period of ten to twenty years (Figures 36, 37). Of interest in this group is the fact that in some patients there may be no progression of the disease in the arterial bed at the original site after surgical correction, but ten or more years later, the disease appears in another arterial bed.

Determination of the susceptibility of the individual patient to these different rates of progression is obviously highly desirable. Unfortunately, in our present state of knowledge, this has not been possible to accomplish. Analysis of our experience has not demonstrated a strong correlation between individual risk factors, such as hypercholesterolemia, smoking, and hypertension, and the various rates of progression. Moreover, about one-fourth of the patients have no identifiable risk factor. It would thus appear that the disease complex referred to as arteriosclerosis or atherosclerosis represents a number of distinctively different clinical and anatomicopathologic patterns with various rates of progression.

References

1. Roentgen WC: Ueber eine neue art von strahlen. *Sitzungsberichte der Wurzburger Physik-medic Gesellschaft.* p 137, 1895. Translation: On a new kind of rays. *Science* 3: 227; 726, 1896.
2. Haschek E, Lindenthal OT: Ein Beitrag zur praktischen Verwerthung der Photographie nach Röntgen. *Wien Klin Wochenschr* 9: 63, 1896.
3. Berberich J, Hirsch S: Die Röntgenographische darstellung der arterien und venen am lebenden Menschen. *Klin Wochenschr* 2: 2226, 1923.
4. Brooks B: Intra-arterial injection of sodium iodide. Preliminary report. *JAMA* 82: 1016, 1924.
5. Moniz E: L'encéphalographie artérielle, son importance dans la localization des tumeurs cérébrales. *Rev Neurol* 48: 72, 1927.
6. dos Santos R, Lamas AC, Pereira-Caldan J: Arteriografia da aorta e dos vasos abdominais. *Med Contemp* 47: 93, 1929.
7. Swick M: Intravenous urography by means of Uroselectan. *Am J Surg* 8: 405, 1930.
8. Binz A, Räth C: Uber biochemische Eigenschaften von Derivaten des Pyridins und Chinolins. *Biochem Z* 203: 218, 1928.
9. Lambert: Cited by Rich NM, Spencer FC: Vascular Trauma, p 6. Philadelphia, WB Saunders, 1978.
10. Czerny V: Cited by Matas R: Surgery of the vascular system, Chap 70, p 171. Surgery: Its Principles and Practices (Keen WW, DaCosta JC, eds). Philadelphia, WB Saunders, 1909.
11. Postempski P: La sutura dei vasi sanguini. Researche sperimentali. *Arch Soc Ital Chir, Roma* 3: 391, 1886.
12. Matas R: Traumatic aneurism of the left brachial artery. *Med News* 53: 462, 1888.

13. Eck N: Cited by Ellis FH Jr: Principles in arterial and venous surgery, p 677. Peripheral Vascular Diseases (Fairbairn JF II, Juergens JL, Spittell JA Jr, eds). Philadelphia, WB Saunders, 1972.
14. Murphy JB: Resection of arteries and veins injured in continuity—end-to-end suture—experimental and clinical research. *Med Rec* 51: 73, 1897.
15. Dörfler J: Uber Arteriennaht. *Beitr z klin Chir* 25: 781, 1889.
16. Payr E: Beiträge zur Technik der Blutgefäss- und Nervennaht nebst Mittheilungen über die Verwendung eines resorbirbaren Metalles in der Chirurgie. *Arch f klin Chir* 62: 67, 1900.
17. Carrel A: The surgery of blood vessels. *Bull Johns Hopkins Hosp* 18: 18, 1907.
18. Guthrie GC: Blood-vessel Surgery and its Application. London, Longmans, Green & Company, 1912.
19. Bode E, Fabian E: Ueber die Transplantation freier und konservierter Gefässe. *Beitr z klin Chir, Tubing,* 66: 67, 1910.
20. Jassinowsky A: Ein Beitrag zur Lehre von der Gefässnaht. *Arch f klin Chir* 42: 816, 1891.
21. Crafoord C, Nylin G: Congenital coarctation of the aorta and its surgical treatment. *J Thoracic Surg* 14: 347, 1945.
22. Gross RE: Surgical correction for coarctation of the aorta. *Surgery* 18: 673, 1945.
23. Gross RE, Bill AH Jr, Peirce EC II: Methods for preservation and transplantation of arterial grafts. Observations on arterial grafts in dogs. Report of transplantation of preserved arterial grafts in 9 human cases. *Surg Gynecol Obstet* 88: 689, 1949.
24. Gross RE: Treatment of certain aortic coarctations by homologous grafts; report of nineteen cases. *Ann Surg* 134: 753, 1951.
25. Hufnagel CA: Preserved homologous arterial transplants. *Bull Am Coll Surg* 32: 231, 1947.
26. Oudot J: La greffe vasculaire dans les thromboses du carrefour aortique. *Presse med* 59: 234, 1951.
27. Leriche R: Des obliterations artérielles hautes (obliteration de la terminaison de l'aorte) comme causes des insuffisances circulatoires des membres inférieurs. *Bull Mém Soc Chir (Paris)* 49: 1404, 1923.
28. Dubost C, Allary M, Oeconomos N: Resection of an aneurysm of the abdominal aorta. Reestablishment of continuity by preserved human arterial graft, with result after five months. *Arch Surg* 64: 405, 1952.
29. Voorhees AB Jr, Jaretzki A III, Blakemore AH: The use of tubes constructed from Vinyon "N" cloth in bridging arterial defects. A preliminary report. *Ann Surg* 135: 332, 1952.
30. DeBakey ME, Cooley DA, Crawford ES, Morris GC Jr: Clinical application of a new flexible knitted Dacron arterial substitute. *Am Surg* 24: 862, 1958.
31. DeBakey ME, Cooley DA, Crawford ES, Morris GC Jr: The clinical application of a new flexible knitted Dacron arterial substitute. *Arch Surg* 77: 713, 1958.
32. dos Santos JC: Sur la désobstruction des thromboses artérielles anciennes. *Mém Acad de Chir* 73: 409, 1947.
33. Kunlin J: Le traitement de l'ischémie artéritique par la greffe veineuse longue. *Rev chir* 70: 206, 1951.
34. DeBakey ME, Crawford ES, Morris GC Jr, Cooley DA: Patch graft angioplasty in vascular surgery. *J Cardiovasc Surg* 3: 106, 1962.
35. DeBakey ME: Basic concepts of therapy of arterial disease. *JAMA* 186: 484, 1963.
36. DeBakey ME: Some observations on the localizing patterns of arteriosclerosis. *Chicago Med Soc Bull* 63: 487, 1960.
37. DeBakey ME: Basic concepts of therapy in arterial disease. *Bull NY Acad Med* 39: 704, 1963.
38. DeBakey ME: Patterns of atherosclerosis and rates of progression, p 1. Atherosclerosis Reviews, Vol 3 (Paoletti R, Gotto AM Jr, eds). New York, Raven Press, 1978.
39. DeBakey ME, Crawford ES, Cooley DA, Morris GC Jr: Surgical considerations of occlusive disease of innominate, carotid, subclavian, and vertebral arteries. *Ann Surg* 149: 690, 1959.
40. DeBakey ME: Concepts underlying surgical treatment of cerebrovascular insufficiency, p 310. Clinical Neurosurgery, Vol X (Mosberg WH Jr). Baltimore, Williams and Wilkins, 1964.
41. DeBakey ME: Successful carotid endarterectomy for cerebrovascular insufficiency. Nineteen-year follow-up. *JAMA* 233: 1083, 1975.
42. DeBakey ME, Morris GC Jr, Jordan GL Jr, Cooley DA: Segmental thrombo-obliterative disease of branches of aortic arch. Successful surgical treatment. *JAMA* 166: 998, 1958.
43. DeBakey ME: Changing concepts in vascular surgery. *J Cardiovasc Surg* 1: 3, 1960.
44. DeBakey ME, Morris GC Jr, Crawford ES, Cooley DA: Surgical considerations of renal hypertension. *J Cardiovasc Surg* 2: 435, 1961.
45. DeBakey ME, Creech O Jr, Cooley DA: Occlusive disease of the aorta and its treatment by resection and homograft replacement. *Ann Surg* 140: 290, 1954.
46. DeBakey ME, Cooley DA, Creech O Jr: Aneurysm and occlusive diseases of the aorta: analysis of 203 cases treated by resection and homograft replacement, p 468. Cardiovascular Surgery (Proceedings of Symposium, Henry Ford Hospital, Detroit, March 1955), (Lam CR, ed). Philadelphia, WB Saunders, 1955.
47. DeBakey ME, Crawford ES, Cooley DA, Morris GC Jr: Surgical considerations of occlusive disease of the abdominal aorta and iliac and femoral arteries: analysis of 803 cases. *Ann Surg* 148: 306, 1958.
48. DeBakey ME, Cooley DA: Surgical considerations of acquired diseases of the aorta. *Ann Surg* 139: 763, 1954.
49. Baker NH, Grindlay JH: Technic of experimental systemic-to-coronary-artery anastomosis. *Proc Staff Meet, Mayo Clin* 34: 497, 1959.
50. Moore TC, Riberi A: Maintenance of coronary circulation during systemic-to-coronary-artery anastomosis. *Surgery* 43: 245, 1958.
51. Murray G, Porcheron R, Hilario J, Roschlau W: Anastomosis of a systemic artery to the coronary. *Can Med Assoc J* 71: 594, 1954.
52. Thal A, Perry JF Jr, Miller FA, Wangensteen OH: Direct suture anastomosis of the coronary arteries in the dog. *Surgery* 40: 1023, 1956.
53. DeBakey ME, Henley WS: Surgical treatment of angina pectoris. *Circulation* 23: 111, 1961.
54. Absolon KB, Aust JB, Varco RL, Lillehei CW: Surgical treatment of occlusive coronary artery disease by endarterectomy or anastomotic replacement. *Surg Gynecol Obstet* 103: 180, 1956.
55. Cannon JA, Longmire WP, Kattus AA: Considerations of the rationale and technique of coronary endarterectomy for angina pectoris. *Surgery* 46: 197, 1959.
56. Sabiston, DC Jr: Coronary endarterectomy. *Am Surg* 26: 217, 1960.
57. Bailey CP, May A, Lemmon WM: Survival after coronary endarterectomy in man. *JAMA* 164: 641, 1957.
58. Kattus AA, Longmire WP, Cannon JA, Winfield ME, Davis JH: Diagnostic and functional evaluation of candidates for coronary endarterectomy. *Arch Int Med* 104: 870, 1959.
59. Longmire WP Jr, Cannon JA, Kattus AA: Direct-vision coronary endarterectomy for angina pectoris. *N Engl J Med* 259: 993, 1958.
60. Garrett HE, Dennis EW, DeBakey ME: Aortocoronary bypass with saphenous vein graft. Seven-year follow-up. *JAMA* 223: 792, 1973.
61. DeBakey ME: Discussion of Blakemore AH: Progressive constrictive occlusion of the aorta with wiring and electrothermic coagulation for the treatment of arteriosclerotic aneurysms of the abdominal aorta. *Tr South S A* 64: 202, 1952.

62. DeBakey ME, Cooley DA: Surgical treatment of aneurysm of abdominal aorta by resection and restoration of continuity with homograft. *Surg Gynecol Obstet* 97: 257, 1953.
63. DeBakey ME, Cooley DA: Successful resection of aneurysm of thoracic aorta and replacement by graft. *JAMA* 152: 673, 1953.
64. DeBakey ME, Cooley DA: Successful resection of aneurysm of distal aortic arch and replacement by graft. *JAMA* 155: 1398, 1954.
65. DeBakey ME, Cooley DA, Crawford ES, Morris GC Jr: Aneurysm of the thoracic aorta: analysis of 179 patients treated by resection. *J Thorac Surg* 36: 393, 1958.
66. DeBakey ME, Cooley DA: Excisional therapy of aortic aneurysms. *Am Surg* 19: 603, 1953.
67. DeBakey ME: Changing concepts in thoracic vascular surgery. *J Thorac Cardiovasc Surg* 38: 145, 1959.
68. DeBakey ME, Crawford ES, Cooley DA, Morris GC Jr: Successful resection of fusiform aneurysm of aortic arch with replacement by homograft. *Surg Gynecol Obstet* 105: 657, 1957.
69. DeBakey ME, Cooley DA, Creech O Jr: Surgery of the aorta. *Clinical Symposia, Ciba* 8: 45, 1956.
70. DeBakey ME, Creech O Jr, Morris GC Jr: Aneurysm of thoracoabdominal aorta involving the celiac, superior mesenteric, and renal arteries. Report of four cases treated by resection and homograft replacement. *Ann Surg* 144: 549, 1956.
71. DeBakey ME, Crawford ES, Garrett HE, Beall AC Jr, Howell JF: Surgical considerations in the treatment of aneurysms of the thoracoabdominal aorta. *Ann Surg* 162: 650, 1965.
72. DeBakey ME, Cooley DA, Creech O Jr: Surgical considerations of dissecting aneurysm of the aorta. *Ann Surg* 142: 586, 1955.
73. DeBakey ME, Henley WS, Cooley DA, Crawford ES, Morris GC Jr: Surgical treatment of dissecting aneurysm of the aorta: analysis of seventy-two cases. *Circulation* 24: 290, 1961.